F. R. Hutton.

PRESIDENT 1907

OF

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

THE AMERICAN SOCIETY
OF MECHANICAL ENGINEERS

TRANSACTIONS

VOLUME 29

INDIANAPOLIS MEETING
NEW YORK MEETING
1907

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THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

1907

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THURSTON, R. H.	1880–1882	Died Oct. 25, 1903
LEAVITT, E. D.	1882–1883	Cambridge, Mass.
SWEET, JOHN E.	1883–1884	Syracuse, N. Y.
HOLLOWAY, J. F.	1884–1885	Died Sept. 1, 1896
SELLERS, COLEMAN	1885–1886	Philadelphia, Pa.
BABCOCK, GEORGE H.	1886–1887	Died Dec. 16, 1893
SEE, HORACE	1887–1888	New York, N. Y.
TOWNE, HENRY R.	1888–1889	New York, N. Y.
SMITH, OBERLIN	1889–1890	Bridgeton, N. J.
HUNT, ROBERT W.	1890–1891	Chicago, Ill.
LORING, CHARLES H.	1891–1892	Brooklyn, N. Y.
COXE, ECKLEY B.	1892–1894	Died May 13, 1895
DAVIS, E. F. C.	1894	Died Aug. 6, 1895
BILLINGS, CHARLES E.[1]	1895	Hartford, Conn.
FRITZ, JOHN	1895–1896	Bethlehem, Penn.
WARNER, WORCESTER R.	1896–1897	Cleveland, O.
HUNT, CHARLES WALLACE	1897–1898	New York, N. Y.
MELVILLE, GEORGE W.	1898–1899	Philadelphia, Pa.
MORGAN, CHARLES H	1899–1900	Worcester, Mass
WELLMAN, S. T.	1900–1901	Cleveland. O.

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REYNOLDS, EDWIN	1901–1902	Milwaukee, Wis.
DODGE, JAMES M.	1902–1903	Philadelphia, Pa.
SWASEY, AMBROSE	1903–1904	Cleveland, O.
FREEMAN, JOHN R.	1904–1905	Providence, R. I.
TAYLOR, FRED. W.	1905–1906	Philadelphia, Pa.

[NOTE.—According to the Constitution, Article C 27, the five surviving Past Presidents who last held the office shall be members of the Council, with all the rights, privileges and duties of the other members of the Council.]

[1]Unexpired term of E. F. C. Davis

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1907

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Ambrose Swasey (4)
Leonard Waldo (5)

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Frederick R. Hutton (*Chairman*)
Fred W. Taylor
Calvin W. Rice
John W. Lieb. Jr.
Fred J. Miller

[1] H. H. Suplee was appointed to fill the unexpired term of Henry R. Towne.

Note.—Numbers in parentheses indicate length of term in years that the member is yet to serve.

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FREDERICK REMSEN HUTTON

FREDERICK REMSEN HUTTON, PRESIDENT OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, 1907

There is probably no one person whose career has been more intimately connected with The American Society of Mechanical Engineers than Prof. F. R. Hutton. For twenty-three years he filled the office of Secretary, during which time the Society grew from a membership of 364 to 3366, an increase of 3000, and when in 1906 he was elected President of the Society, its commanding position among the national professional societies had long been assured.

Professor Hutton was born in New York, May 28, 1853. After preparation in a private school in New York, he entered Columbia College, receiving the degree of A.B. in 1873. After graduation he entered the School of Mines, and was given its degree in 1876. A year later he was appointed instructor in mechanical engineering as an associate of the late Prof. W. P. Trowbridge. This was the first recognition which Columbia gave to the important relations of mechanical engineering to other engineering courses. He entered the faculty as adjunct professor in 1881 and became professor in 1890. Upon the death of Professor Trowbridge, in 1892, the chair of engineering which he occupied was divided, and professorships in civil engineering and electrical engineering were added to the already existing professorships of mining and mechanical engineering. Professor Hutton was made the head of the mechanical department. He continued to direct this department until his resignation, July 1, 1907. At this time he resigned and was elected professor emeritus. For six years during his professorship he was Dean of the Faculty of Applied Science.

During Professor Hutton's association with the university he developed the mechanical laboratories until the equipment at present is the most complete of any technical school. It includes a Baldwin compound locomotive mounted upon its testing equipment, a triple expansion Allis-Reynolds engine, and also a three-stage air compressor, and the hydraulic equipment of the Henry R. Worthington laboratory. The equipment has been valued at $100,000.

Columbia conferred upon Professor Hutton, in 1882, the degree of Ph.D., and upon the occasion of its one hundred and fiftieth anniversary, in 1904, the degree of Sc.D.

Professor Hutton became Secretary of the Society in 1883, three years after its organization, when its offices were located at 17 Cortlandt Street. He continued to direct its activities during the years following when it was located successively at 280 Broadway (The Stewart building), 84 Madison Avenue, and 12 West 31st Street. In 1890 the house at 12 West 31st Street was purchased for $60,000, and sold in 1906 for $120,000, realizing a profit of nearly $60,000. Professor Hutton took an active part in this important and successful transaction, and became one of the Trustees of the Mechanical Engineers Library Association, organized to hold the property. One of the most remarkable events in the history of the Society was the trip made to Europe in 1889. Professor Hutton was connected with the arrangements for this trip, which has had a wide influence in giving international recognition to the Society and establishing the bond of professional fellowship between this and the countries visited.

Professor Hutton was the member appointed by this Society of the Conference and Building Committee of the United Engineering Society. This Committee was organized to plan the new Engineering Societies' Building at 29 West 39th Street, and during its erection considered the problems and attended the execution of the details which make the building one of the most complete of modern structures. Professor Hutton is also one of the Board of Trustees, which is the holding corporation for the United Engineering Society.

He declined reëlection to the office of Secretary in January 1906, and at the Annual meeting, the following December, was unanimously elected president. Professor Hutton's many years of service made it particularly fitting that he should be the first president at the opening of this new era of prestige and prosperity for engineering.

In addition to the work for the Society and at Columbia University, Professor Hutton has been a contributor to scientific literature. His most important books, which have received considerable acceptance in the educational field in the United States and in England, are "The Mechanical Engineering of Power Plants," "Heat and Heat Engines," and "The Gas Engine." The first of these is used as a text book in some of the technical institutions of Japan. He was the author of two of the most important monographs of the Census of 1880, one covering machine tools and the other pumps and pumping engines.

He has contributed to the Transactions of the Society over his own name, with unsigned contributions, and memorial monographs and discussions. "Mineral Wool as a Non-Conductor Around Steam Pipes;" "First Stationary Steam Engines in America;" "A Classification and Catalogue System for an Engineering Library;" "The Mechanical Engineer and the Function of the Engineering Society." He has done considerable editorial work as associate editor of Johnson's Encyclopedia, as one of the editors of scientific and engineering titles of the Century Dictionary, as Departmental editor in the Engineering Magazine, and has been a contributor to technical journals and a lecturer to scientific and popular audiences in New York and elsewhere.

At the close of Professor Hutton's administration as president he was appointed by the Council to the office of Honorary Secretary.

Calvin W. Rice

SECRETARY

OF

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

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[illegible]

Mr. Calvin W[illegible] [illegible] of engineering [illegible] [illegible] temperament, [illegible] qualified to fill [illegible] engineering bodies, [illegible] wide usefulness.

Mr. Rice was born [illegible] Winchester, [illegible] and received his early [illegible] and Winchester. [illegible] Massachusetts Institute of Technology in 18[illegible], [illegible] He was already [illegible] after some practical [illegible] subordinate positions [illegible] engineer in the Power [illegible] Company, at [illegible] with the General Electric Company [illegible] to the Schenectady works. [illegible] greater responsibilities as [illegible] with headquarters at Cincinnati, [illegible] many branches of [illegible] engineering [illegible] railway, lighting, power and mining.

CALVIN WINSOR RICE

The New Secretary of The American Society of Mechanical Engineers

BY JOHN W. LIEB, JR.

Mr. Calvin Winsor Rice has seen considerable service in the councils of engineering societies, and during 1906 he was chairman of the committee of papers and meetings of the Mechanical Engineers. By temperament, education, and professional experience he is peculiarly qualified to fill the position of secretary of one of the most influential engineering bodies, and it opens to him a career of distinction and wide usefulness.

Mr. Rice was born at Winchester, Mass., on November 4, 1868, and received his early education in the public schools of Boston, New Haven and Winchester. He entered the Massachusetts Institute of Technology in 1886, graduating from the course in electrical engineering. He was already familiar with the handling of machine tools, and, after some practical experience in the drafting room and in various subordinate positions, was advanced to the position of assistant engineer in the Power and Mining Department of the Thomson-Houston Company, at Lynn, Mass. When the consolidation with the General Electric Company took place Mr. Rice was transferred to the Schenectady works. He was soon advanced to a position of greater responsibilities as district engineer of the company, with headquarters at Cincinnati, a field in which his services were called upon in many branches of electrical engineering work—railway, lighting, power and mining.

He then turned his attention to mining work, and after service in the Silver Lake Mines, at Silverton, Col., he became connected, as consulting engineer, with the Anaconda Copper Mining Company, of Butte, Mont. There he obtained a wide experience in the development of water-powers, in their transmission electrically to distant points and in the economical handling of large steam plants. Returning to the East, he was appointed electrical engineer of the Kings

County Electric Light and Power Company, and later took part in the engineering work in connection with the consolidation of the lighting plants in the boroughs of Manhattan and the Bronx, of the city of New York, under the auspices of the New York Light, Heat and Power Company, succeeded by the New York Edison Company. As engineer in charge of one of the operating departments of the company and engineer of the company operating the high-tension subways of New York City, he became thoroughly familiar with all branches of central station work.

In 1902 Mr. George Westinghouse was preparing to introduce the Nernst lamp to the American public, and Mr. Rice received a call to direct the work as second vice-president and manager of the Nernst Lamp Company. The year following he returned to the service of the General Electric Company as consulting engineer of the New York office where he made a specialty of steam engineering, with particular reference to steam turbines.

Mr. Rice is a member of The American Institute of Electrical Engineers, and The Institution of Electrical Engineers.

MONTHLY MEETINGS

HELD IN NEW YORK ON JANUARY 8,
FEBRUARY 12, MARCH 21, APRIL 18, 1907

REGULAR MONTHLY MEETINGS

STATUS OF PAPERS PRESENTED AT THE MONTHLY MEETINGS

The Council decided at a meeting on April 16 that—as heretofore the Society had not held regular monthly meetings and that as such monthly meetings had not been specifically mentioned in the Constitution and By-Laws or Rules of the Society as having official recognition—it was the sense of the Council that monthly meetings now be considered as official, and that they offer equal opportunity with the annual and spring meetings for the presentation of technical papers and discussions, and that the same shall be considered by the Publication Committee for the Transactions equally as if they had been presented at the annual or spring meeting.

THE JANUARY MEETING

In January 1907, the Society began holding regular monthly meetings on the second Tuesday of each month. The January meeting, Tuesday evening, January 8, the first meeting of the Society in the new building, was addressed by Frederick P. Fish, Esq., of Boston, President of the American Telephone and Telegraph Company, the subject being "The Ethics of Trade Secrets." Mr. Fish is not only one of the most eminent attorneys of America, but has made a specialty of patent causes. His address was a logical treatment of a subject which has been of great interest since the beginning of modern industries. It is published in this volume. The meeting was presided over by the President.

THE FEBRUARY MEETING

At the February meeting held on Tuesday evening, February 12, "The Testing of Inflammable Gases" was treated by C. E. Sargent, of Chicago, Ill., and Prof. Charles M. Allen of Worcester Polytechnic Institute delivered a lecture on gasolene in which he made experiments showing the chemical combinations necessary to produce an explosive gas and the combination of air and gas for producing an inflammable liquid.

THE MARCH MEETING

Mr. John W. Lieb, Jr., Vice-President of the Society, addressed a large audience in the main Auditorium on the evening of March 21. The lecture, delivered on the occasion of the regular monthly meeting, was on "Vesuvius and the Mechanic Arts of Pompeii," giving the history of the eruptions of Vesuvius and a description of the life and customs of Pompeii from the earliest record down to the present time.

The lecturer spoke of volcanic heat as a source of energy as yet practically without utilization, and as a field of investigation for the engineering profession, taking up also the character of volcanic activity, computing the enormous pressure necessary to sustain the columns of lava erupted from the craters—which are in many cases a thousand feet deep—and to force them a thousand feet or more into the air.

He explained the accepted causes of volcanic activity, the theories of volcanic phenomena, and the products of eruption—giving a scientific analysis of their composition.

A brief historical sketch of the eruptions of Vesuvius, beginning in 63 A. D., followed, including the letters of Pliny the Younger to Tacitus, in which there is a graphic description by an eye-witness of the terrible catastrophe of 79.

The descriptions and pictures of the city of Pompeii; the streets, the baths, the homes, the temples, and the amphitheatre formed a valuable part of the lecture. A picture was shown of an interesting relic called the Table of Standard Measures which is the first evidence of standardization of which we have any record. These standards were adopted during the rule of Augustus.

Many of the slides were specially imported. Some were taken by the author, others by Mr. Frank Perret of Brooklyn, who was in the Vesuvian Observatory during the eruption in 1906, and others were reproductions from drawings.

Moving pictures taken in April of last year were shown by Mr. E. Burton Holmes, the eminent travelogue author and lecturer. Among them were pictures of Vesuvius in eruption, a panorama of lava, a flowing stream of molten lava, terrific outbursts of smoke, steam, sand and ashes, refugees leaving San Guiseppe and Ottaiano, and Vesuvius in fury as seen from Naples at sunrise.

THE APRIL MEETING

The April meeting, which was the last monthly meeting of the season, was held on Thursday evening, April 18, during the week of Dedication, and was addressed by Brigadier-General William Crozier, Chief of Ordnance of the United States Army. The paper, which is published in this volume is upon "The Ordnance Department as an Engineering Organization," and stands as an unique address in the Transactions of the Society.

No. 1137

THE ETHICS OF TRADE SECRETS

BY FREDERICK P. FISH, ESQ., BOSTON, MASS.

Non-Member

The trade secret that interests us today as a practical and substantial feature of our industrial relations can not be considered apart from the law which defines it and alone determines its extent and character as a thing capable of discussion. In so far as such a secret is protected, it may be regarded as a species of property. It is, however, obviously not tangible property, like lands or chattels. It is not even of the class represented by stocks, bonds, or other securities. Its legal recognition implies a right to a thing that is intangible; to an idea or plan. In this respect, it may be compared not only with property in inventions, in so far as the same are protected by letters patent, but with the limited rights which an author has to his literary productions, and the artist, musician, or playwright to the creations of his imaginative effort. Trademarks, and the right to check unfair competition which has grown out of the trademark law, are other forms of intangible property which the law protects.

2 It is only at a comparatively high stage of development in a community that the law recognizes and deals with such intangible rights. Early jurisprudence is largely concerned with personal rights and with tangible property. It is filled with provisions as to the maintenance and support of the complicated relations which in primitive times characterized family, social, and political life. As society advances, the idea of individualism develops, and freedom of action is encouraged. As pointed out by Sir Henry Maine, "contract," that is, relations voluntarily established by individuals, becomes more and more important, and "status," which is the condition imposed upon the individual by his environment, that is to say, by the accident of his having been born in a certain station in a certain community and at a certain time, becomes less controlling.

3 This change from status to contract has clearly characterized

Presented at the monthly meeting, January 8, 1907 (New York), of The American Society of Mechanical Engineers, and forming part of Volume 29 of the Transactions.

the development of the English speaking race to which, as a matter of institutions if not altogether of blood, we belong. Involved in it, has been a growing recognition of the right of a man to that which was his own. This was inevitable if individual effort was to be fostered and men were to be free to deal with each other by contract. If public sentiment requires that the effort of each citizen shall be encouraged to the utmost and that no one shall have the direct benefit of another's contribution to productive power without his consent, it is inevitable that the familiar doctrine of property rights should be extended so as to include things, some of them of great value, which in an earlier social organization were not conceived of as subject to a legally protected individual ownership.

4 We all know how astonishing have been the advances in material prosperity during the past hundred years. He would be a bold theorizer who would contend that this advance has not been due, in part at least, to the fact that during all that period individual initiative has been fostered by public sentiment, and by the law which in the long run reflects the prevailing public sentiment.

5 It is during this hundred years that the right to the intangible properties to which I have referred has for the most part been crystallized into such shape as to be capable of definite expression. Letters patent for inventions, to be sure, grew out of the exception in the Statute of James I. (1623–1624), which declared monopolies, so long a source of revenue to the British kings and of hardship to the subjects, to be illegal except when granted for a limited term for a new manufacturer; but the important development of patents and of patent law as an essential part of the prevailing industrial scheme, did not really begin either in Great Britain or in this country until well into the 19th century.

6 In 1742, the great Chancellor, Lord Hardwicke, declared that while every trader had his distinctive mark or stamp, he knew of no precedent for enjoining one trader from using another's mark, and he thought such precedent would be mischievous. In 1803, such a precedent was established by Lord Eldon, in the case of Hogg v. Kirby, 8 Ves. 215. From this time the law grew rapidly. Its progress has been especially marked during the past thirty years.

7 The definite development of the law of copyright, both that which is based on statute and that which is independent of legislative enactment, is in like manner comparatively modern. The first trade secret case was decided less than one hundred years ago.

8 In all the classes of rights to which I have just referred, there is this in common: Ideas or thoughts or plans or schemes which are of

value to the one who rightfully possesses them, are secured to him to a greater or lesser extent by the law. In the case of a trademark, and of the cognate law preventing unfair competition, what is secured to the owner is a monopoly of the benefit which comes from the impression associated with the shape or appearance or brand of an article of manufacture which, lingering in the mind of the buyer, influences him in subsequent purchases to take what he believes to be goods of the same make as those which he bought before. There is a special analogy between trade secrets and letters patent for inventions on the one hand and common law and statutory copyright on the other. I shall again refer to this.

9 The trade secret, as we know it, as defined and determined by our rules of law which alone give it body and character is, therefore, a comparatively modern institution. But there was a long history of trade secrets prior to our common law recognition of them. It may be interesting to note briefly the great part that they have played in the industries under conditions that have now passed away.

10 In all ages many trade secrets have been in the possession of individuals, but for a long period of time they also were a great asset of trading communities and frequently of guilds or associations. Every effort was made to preserve them for the few who had the benefit of them. Always and everywhere those who did not have the secrets sought to learn them. While not as a rule protected by systematic rules of law, kings and governments often intervened to aid their subjects to preserve the secrets they had, and to learn those which they did not know. All this was in accordance with the underlying laws of human nature which prevail even to this day. It was a phase of the struggle for advancement that has characterized all progress. As in all other phases, the struggle was carried on by each generation according to the standards of the time, and those standards were sometimes not high. It seems clear, however, that the right to preserve a trade secret if one could, and to an equal degree the right to get the secret of another by any means not offensive to the current moral sense, were always recognized.

11 The history of the silk industry, up to a comparatively modern time, was largely confined to the disclosure of the secrets of the East to the people of the West, and later of one Western community to another. The mysteries of cloth manufacture and of dyeing were jealously guarded all through the Middle Ages. There are dramatic stories of the way in which such secrets were carried from one place to another. We read of James I. of England smuggling three skilled workmen in hogsheads from France to instruct his British subjects in the secret process of manufacturing the alum used in dyeing.

12 Many community trade secrets were disseminated by the religious persecution of the 16th and 17th centuries which drove from the Netherlands and from France, Protestant skilled workmen who were in the possession of those secrets. This had much to do with the development of industries in England, Germany and Switzerland. In particular, the revocation of the Edict of Nantes exiled from France thousands of Huguenot workmen, who were thus forced by the action of their own government to introduce into foreign countries secrets of French trade and manufacture, which otherwise might not have been discovered for years.

13 The modern art of hat making prior to the revocation of the Edict of Nantes, had been entirely in the hands of certain of the French Protestants. They alone possessed the secret of the liquid composition which served to prepare properly the hare, rabbit, and beaver skins used in hat making. So many of them were driven to England that the secret of their art was lost to France for more than 40 years, during which time the French nobility and all persons making pretense to elegance in dress, wore nothing but English hats. Finally about the middle of the 18th century, a French hatter, named Mathieu, who was working in London, stole the secret which the refugees had taken away and carried it back to France, where the industry was reëstablished. No greater blow was ever inflicted upon the industries and trade of a nation than in France by the revocation of the Edict of Nantes.

14 The great family of the Medici in the 16th century had a trade secret relating to the manufacture of a soft porcelain, which was subsequently lost, probably because it was too carefully guarded.

15 About the year 1710, John Frederic Böttger, who was in the employ of Frederic Augustus, Elector of Saxony, discovered the secret of making real porcelain. His master, the Elector, resolved that the discovery should remain a trade secret. He therefore kept Böttger in close confinement until his discovery was perfected to the point of finished work. He then established a factory within the fortress of Albrechtsburg. The drawbridge was always raised; none but the workmen could enter or leave the factory and they were bound by a solemn oath to keep until death the secret, if by accident they learned it. They knew that the severest punishment would follow any betrayal. This was the origin of the famous Dresden or Meissen ware. The secret of the Saxon Elector was, however, preserved only for a short time. About 1745, a runaway workman carried it to Vienna, where under royal patronage factories were established to practice it, which have turned out masterpieces of the potter's

art. The secret was also carried to France about 1770, when the manufacture of the Sèvres pottery began.

16 Long after the Flemish refugees driven from the Netherlands by the religious persecutions of Philip II. had come to England, they kept to themselves as trade mysteries the manufacture of felt, and the making of certain brass ware for culinary purposes.

17 The establishment of the first glass factory in England was the result of the theft of a trade secret. An English admiral, angered by having been refused admittance to a French factory, hired away one of the workmen from that factory and founded an establishment at Ravenshead, Lancashire, which has continued almost if not quite to the present time.

18 The secrets of the production of Venetian glass ware were guarded with most jealous care. No strangers could learn the art. Any workman carrying his skill to another country was followed and ordered back. If he refused to return, his relatives were imprisoned. If he still persisted, his life was in danger. It is recorded that a wandering Venetian glass maker named Paoli was followed to Normandy, where he was stabbed with a dagger on which was written the word "Traitor."

19 The East, as it always has been, is today a great field for trade secrets. We of the West do not know the mysteries of crackled china, of lace work, translucent porcelain covered with glaze, or of the marvelous egg shell cups and the process whereby they are enameled and covered with a finely woven case of bamboo. The same is true of many processes for the manipulation of metals and amalgams, which are known to the workmen of Japan and by which are produced effects beyond the reach of the workmen of other countries.

20 The two oldest secret trade processes now in existence are said to be the manufacture of Chinese red or vermilion, and the Damascus art of inlaying hardened steel with gold and silver.

21 Up to the capture of the city by Tamerlane, the Damascus blade was the most famous weapon in the world. It could cut iron or gauze floating in the air. Tamerlane carried all the weapon makers of the captured city into Tartary where they continued their work. Their descendants are said to be skilled smiths in Samarcand to this day; but no more of such blades were produced in Damascus. One can buy Damascus weapons there today, but they are mostly "made in Germany."

22 Always and everywhere there has been a constant effort to discover the secrets of rival manufacturers or of rival communities. An interesting story on the subject is that of the Venetian, Braarti,

who in the 18th century obtained a knowledge of the methods practiced in the Bohemian Glass Works by disguising himself as a porter and serving for three years in a glass factory in order that he might take home with him certain mysteries of the Bohemian art that were not known in his native city.

23 The day of the guild or trade association has long passed away. The time has also passed when, except in the East, a state or even an isolated community can hope to monopolize a trade secret which is shared by a substantial number of people. The ties which bind the workmen in any craft to their employer or to any comprehensive trade organization have long been among the Western nations too loose to prevent the dissemination of any trade device or method which is known to a large number of people. It can be no longer a secret if all those working in a trade in any locality are familiar with it.

24 A reference to these trade secrets of the olden time, which seems to have had for the most part no definite legal sanction, is only material as affording a basis upon which public sentiment, with the sanction of the law, has given to us our trade secret of today. The whole industrial world was permeated with the idea of trade secrets and of their value. As the trades became more and more matters of individual enterprise, it was but natural that, with this history behind them, the sentiment of the community regarded them as a substantial thing to be dealt with on grounds of public policy. It has dealt with them, through the law, exactly as it has dealt with copyrights and trade-marks, and I believe in a way that is quite in harmony with the general thought of the time.

25 When our law of trade secrets was first formulated less than a century ago, the industrial conditions were nearly as remote from those of the present day as they were from those of the Middle Ages. The trades had, however, come generally into the hands of individuals. We had started on a line of industrial organization and development which has been consistently followed to the present time. Almost the cardinal principle of this line of development has been the encouragement of the individual to risk and effort. It has been generally recognized that the gain to the community would be the greatest if every member of it was stimulated to do his utmost for himself. There is need for encouragement to individual thought and effort. No one is likely to face the trouble, anxiety, and cost of experimenting and testing new ideas, which are sure to fail in the majority of cases with the chance of great loss, unless he can look forward to a substantial reward if he succeeds.

26 This thought was not new with the last century. It has always

existed. Men have always been encouraged to seek individual prosperity as probably the best way to promote the common good. It may well be that the whole doctrine of the right to property, which seems to us instinctive, rests upon this foundation. But with the expanding manufactures, trade, and commerce of the last hundred years, the idea has become dominant as never before and has been definitely reflected in our institutions and laws. Certainly, there can be as a practical matter, no greater stimulus to the individual to do the best there is in him toward building up the industry with which he is concerned, than the certainty that he may secure and maintain for his own use that which he has acquired fairly and honestly according to the standards of his time, part of which is a just proportion of what he has added to the general productive power. If such is the case, the greatest good of the greatest number must require that there should be a gain to him for his contribution to the well being of the community by way of original thought and initiative, as well as by way of good business methods or administrative capacity or ardent labor.

27 There has never been a time when there were not some dissenters from this general view. Those who have been unsuccessful have sometimes failed to admit its validity. Many have speculated as to whether there were not conceivable industrial conditions, perhaps better than those which prevailed, in which so much encouragement would not be given to the individual but in which the requisite effort could be secured on other and less selfish grounds. And there have been times in which the natural and perhaps inevitable development of current industrial methods has been such as to bring about a revulsion of public sentiment, more or less sound, and more or less justifiable, but at any rate to be taken into consideration as definitely affecting the trend of development of industrial ideas and industrial conditions. But it does not seem possible to deny that the general sentiment has almost always been in favor of the encouragement of the individual in his selfish aspirations for personal prosperity.

28 I see nothing in the temper of our own times to indicate that this broad view of what is for the common good has been shaken. Few doubt that an individual should get a personal benefit from his personal skill and energy. We believe that the better and more useful the workman, the more he should have the rewards of life. The public generally agrees that the more one contributes to the progress of the arts as an inventor, the more he should have for his personal use, and that the reward of the tradesman or manufacturer should be based, to a substantial extent, upon the skill, energy, capacity, and

honesty with which he carries on and builds up his business. We know that the entire community profits by the deserved success of any individual in it. We feel instinctively that if the efforts of individuals are attacked or discouraged, all will suffer. The time may come when different views will prevail, but I do not anticipate that such will be the fact.

29 It has of course always been understood that the gain to the individual should be acquired honestly in accordance with the prevailing standards of the time. Sometimes the community has decided that the prevailing standards were wrong, that is to say, inconsistent with the general welfare. Then the standards have been more or less changed and new ones established, occasionally after marked political and business convulsions, but when the convulsions were over and a readjustment to new conditions attained, it has been found that the right of a man to a fitting reward for his contribution to the public well being was respected as much as ever, and that society instinctively proceeded upon the old principle that individuals must be encouraged to prosper as the best known means of securing to the community the gain in productive power and the progress in industrial effort that was essential.

30 It is upon these fundamental principles that the underlying right to the protection of a trade secret, in so far as it is or can be protected, depends. The right is logical and will be asserted and enforced by public sentiment and by the law, which as I have already said is in the long run a reflection of public sentiment, until we cease to believe that individual effort should be encouraged as the most effective stimulus to industrial improvement. When, if ever, doctrines like those of socialism prevail, many rights which seem to us natural and proper may disappear, among them, perhaps, the right to protection against the disclosure of a trade secret to the extent to which that right now exists.

31 A trade secret is some method of manipulating or combining materials, or of controlling or directing the forces of nature, or of organizing machinery, or the details of a business which is the result of original thought, which is of trade value to the person who has the thought or the right to apply it, and which is kept by him a secret that he may get from it a personal advantage not to be directly shared by his competitors. Let us take the simplest possible case. A manufacturer of dyestuffs, through his own ingenuity or thoughtfulness or through the ingenuity or thoughtfulness of others whom he has employed, finds out that his product can be increased or improved or that he can get a new product by a certain process that is not at the

time employed in the art. It is clear that under none of our standards, either of law or of ethics, is the manufacturer under an obligation to use this process or to disclose it to anyone. I doubt if there can ever be any effective law supporting such an obligation, and in the absence of such a law any sentiment of the community, even if it existed, would be inoperative. Neither the law nor the sentiment exists today.

32 The secret, therefore, is the man's own, to keep or to disclose, to use or not to use, as he pleases. No public policy or law can force its disclosure or use. But the one who has it can be encouraged to disclose it or use it, one or both. The patent law offers a reward for the disclosure of secrets of a certain sort, and incidentally encourages their use. I shall have a word to say later as to the bearing of letters patent on the subject, under discussion. The law relating to trade secrets does not tend to promote the disclosure of them, but the contrary. It does encourage their use.

33 If such a secret is of the slightest value, its use as distinguished from its suppression is obviously desirable. If it is suppressed, no one gets any advantage from it. Who is benefited if it is put into use? Is not the answer to this question clear? The possessor of the secret will get some benefit from its use; but the community as a whole is far better off if the secret is utilized. By practicing the secret, the possessor of it will be getting by a given expenditure of capital and of effort, a new product or a cheaper or a better product. He will get a profit for himself; but not all of the profit; some of it will inevitably go to the public. He will be adding to his own wealth, but he will also be adding to the wealth of the state, of which his own wealth forms a part. His business will prosper; he will employ more workmen; the efficiency of his industry will be enlarged; it will be of more general advantage to the community; the well being of society will thereby be advanced. All this follows whenever there is in an art an improvement which is actually utilized. No argument seems to be required to show that society is better off if the new thing is employed in practice, than would be the case if it were not used at all.

34 The possessor of a trade secret, who needs not use or disclose it and who is unwilling to publish it, should therefore surely be encouraged to use it. The law recognizing this fact affords him the only form of encouragement that is really practicable, namely, a certain limited aid in his effort to practice and utilize his secret without losing it. It helps him keep his secret.

35 It has never been suggested that the law should go so far as to protect a trade secret that was not a real secret. Such a proposition

is entirely inconsistent with the common sense and intelligence of mankind. However brilliant may be a thought or an idea, whether it is of value to the industries or to literature or art, when without dishonesty, fraud, or treachery, it has once become known, it is common property. There are men so high minded that they would disdain to use the ideas of others, even if they had the right so to do, but such a view is not universal, and it would be utterly impracticable to seek generally to preserve for one, even if he has originated it, a thought or an idea that has without wrong become disclosed to others, so that it is no longer a secret. But the law can say, to encourage the use of such a secret, that those who are bound by contract or by good faith to aid in keeping it shall be held to their obligation.

36 It is just to this extent and no further that trade secrets are protected. The law does not intervene to protect the secret against discovery by fair and honest means. It does not undertake to make the secret, as such, secure. It only enables it to be utilized, for the good of the possessor and of the public, without danger of betrayal by those who learn the secret in confidence while it is being operated as a secret, and who can betray it only by what the law regards as a breach of honesty and fair dealing.

37 The man who is practising his trade secret must have associates and workmen. Some of them will inevitably learn the secret. Is it not fair and reasonable that, learning the secret under such conditions, they should be forced to respect it? It is by their voluntary act that they enter into such relations. Having established them, should they not be bound by the necessary implication that it was part of the understanding that they should keep what they know to be the valuable secret of the man with whom they are associated? There would seem to be no question in the case of an express contract. Should not a confidential relation clearly involving an implied contract, be equally effective?

38 There may be others, not directly associated with the work, to whom the secret is imparted in confidence. Is it not proper that they should regard that confidence? Does it not appeal to us as right, that those who receive a secret of this sort through a confidential relationship which involves a knowledge of the secret, should respect it and be bound not to disclose it?

39 If the law and public sentiment were otherwise, no trade secret could ever be safely put into use. By holding to what seems to be only a fair standard of business ethics, those who gain a knowledge of the secret through a contract or a confidence that is reposed upon them, are prevented from disclosing it, and the desired result is

accomplished. The possessor of the secret is not, to the detriment of the community, tempted to refrain from using it, but he is encouraged to practice it for the gain there is in it, knowing that so far as he uses it as a secret, those who are in the secret are bound to coöperate with him in protecting it against disclosure.

40 It has been settled by an almost unbroken line of authorities, and it is absolutely clear at the present stage of the law, that a trade secret will be protected against disclosure by anyone who has received it in confidence and under such circumstances that there is a contract, express or implied, that the person to whom the secret was disclosed should himself respect it. It follows that there is also a remedy against those who have received a disclosure of the secret from persons guilty of a breach of confidence or of contract in imparting it, unless they themselves were both entirely honest in the matter and protected by the equities of the situation. Against all others the owner has no redress. He can only invoke the power of the law to make effective an obligation to respect his confidence and to live up to an agreement.

41 The question has most frequently arisen, and is most likely to arise in connection with the employees of one who is actually practising a secret. These men must, from the nature of their employment, know the secret, or be in a position to discover it. In dealing with a case of this sort, an English chancellor, in the case of Morison v. Moat, 9 Hare 241 (21 L. J. Ch. 248), laid down the law in the following words:

> The principles that were argued in this case are principles really not to be called in controversy. There is no doubt whatever that where a party who has a secret in a trade employs persons under contract, express or implied, or under duty express or implied, those persons cannot gain the knowledge of that secret and then set it up against their employer.

42 In Stone et al v. Goss et al, 65 N. J. Eq., 756, the court says:

> These cases establish the principles that employees of one having a trade secret, who are under an express contract, or a contract implied from their confidential relation to their employer, not to disclose that secret, will be enjoined from divulging the same to the injury of their employer, whether before or after they have left his employ; and that other persons, who induce the employee to disclose the secret, knowing of his contract not to disclose the same, or knowing that his disclosure is in violation of the confidence reposed in him by his employer, will be enjoined from making any use of the information so obtained, although they might have reached the same result independently by their own experiments or efforts. We approve the principle thus established.

43 Again in Westervelt et al v. National Paper, etc., Co., 154 Ind. 673, the court says:

> It was the understanding and agreement between appellee and said Taggart

that his ideas and inventions and discoveries concerning said proposed machine should belong to appellee, and it was not contemplated by either party that a patent should be taken out upon anything which he might invent or discover, but that it should be kept a secret. It was a part of the said contract with said Taggart that he should make a complete machine for appellee, and for no other person, and both parties understood by that language that no machine embodying the ideas which said Taggart expected to put into practical form should be made by him for any other person, and his perfected ideas should not be divulged to any other person.

44 Taggart entered the employment of appellee and designed a machine, which appellee completed. Then Taggart entered into a contract with the other appellant for three years to make his machine. and employed the same draftsmen as appellee to furnish drawings.

It is evident from the authorities cited that if a person employs another to work for him in a business in which he makes use of a secret process, or of machinery invented by himself, or by others for him, but the nature and particulars of which he desires to keep a secret, and of which desire on the part of the employer the employee has notice at the time of his employment, even if there is no express contract on the part of the employee not to divulge said secret process or machinery the law will imply a promise to keep the employer's secret thus entrusted to him; and any attempt on his part to use the secret process, or machinery, or to construct the machinery for his own use as against the master or to communicate said secret to others, or in any manner to aid others in using the same. or in constructing the machinery, will not only be a breach of his contract with his employer but a breach of confidence and violation of duty which will be enjoined by a court of equity. * * *

Under the facts alleged, even if no agreement was made, one would be implied that he was not to disclose the secret of the construction of the machine, or impart any information by which anyone could construct such a machine. He occupied a confidential relation to the appellee, and in such case the law raises an implied contract between them that the employee will not disclose any trade secret imparted to him, or discovered by him, in the course of his employment. A disclosure of such secrets thus acquired is not only a breach of contract on his part, but is a breach of trust which a court of equity will prevent.

45 Perhaps the leading case on the subject in this country is that of Peabody et al v. Norfolk et al, 98 Mass. 452, in which Judge Gray, speaking for the Supreme Court of Massachusetts, stated the law as follows:

It is the policy of the law, for the advantage of the public, to encourage and protect invention and commercial enterprise. If a man establishes a business and makes it valuable by his skill and attention, the good will of that business is recognized by the law as property. If he adopts and publicly uses a trade-mark he has a remedy, either at law or in equity, against those who undertake to use it without his permission. If he makes a new and useful invention of any machine or composition of matter, he may, upon filing in a public office a description of which will enable an expert to understand and manufacture it, and thus affording to all persons the means of ultimately availing themselves of it, obtain letters patent from the government securing to him exclusive use and profit for a term of years. If he invents or discovers, and keeps secret, a process of manufacture, whether a proper subject for a patent or not, he has not indeed an exclusive right to it as against the public, or against those who in good faith acquire knowledge of it; but he has a property in it, which a court of chancery will protect against one who, in violation of contract and breach of confidence, undertakes to apply it to his own use or to disclose it to third persons. The jurisdiction in equity to interfere by injunction to prevent such a breach of trust, when the injury would be irreparable and the remedy at law inadequate, is well established by authority.

46 The court then cites a number of the leading cases and concludes by sustaining the right of the court to interfere to protect the disclosure of a trade secret where there is a "violation of contract and breach of confidence."

47 This doctrine is supported by practically an unbroken line of authorities. It is like the doctrines of the common law which protect trademarks, and which prohibit the pirating of unpublished dramatic performances, the publication of letters without the consent of the sender, and many other violations of fundamental and personal rights. It is based upon the conception by the courts of what is for the public interest and what is fair, proper, and honest, as between man and man. There always has to be a legal ground for the application by the courts of a principle of sound morals, and in this connection there is some question in the cases as to whether a trade secret is to be protected as property or because there is a contract, express or implied, or because the disclosure would be a breach of trust.

48 It does not seem profitable at this time to enter upon a discussion of these refinements. For all practical purposes, the views of the courts are based upon a single and simple proposition. An individual is justly and honestly in possession of what is a real trade secret, that is, something useful in his business that is known to him and protected by him to the extent of his power as a secret of his trade. There seems no doubt that this is a real property interest exactly as an invention is property to such an extent that the government can make a contract with reference to it by which it is protected for a limited term by a patent, and exactly as an artistic or literary expression is property and protected as such. In any event, it is obviously unfair that those who have entered into a fiduciary relationship with the possessor of the secret, or who by express contract or by reason of a relationship necessarily implying a contract, have agreed to protect the secret, should undertake to rob the owner of his secret by communicating it to others or using it themselves. The necessity of resenting and checking such unfairness must appeal to all of us as it has invariably appealed to the courts.

49 In a large number of the cases that have been before the courts, there has been no express agreement to protect the trade secret, but only a necessary implication that such an agreement existed, because of the relation of service, or confidential association. As the court said in Robb v. Green (1895), 2 Q. B. 315:

> Where the court sees that there is a matter of this kind which both parties must necessarily have had in their minds when entering into a contract, that is precisely the case in which it ought to imply a stipulation.

50 In Merryweather v. Moore (1892), 2 Ch. 518 (Ch. Div.), the English court said:

> It is sometimes difficult to say whether the court has proceeded on the implied contract or the confidence, for I will put aside once for all any cases arising on express contract. Perhaps the real solution is that the confidence postulates an implied contract; that, when the court is satisfied of the existence of the confidential relation, then it at once infers or implies the contract arising from that confidential relation—a contract which thus calls into exercise the jurisdiction to which I have referred.

51 It is one of the glories of the common law that common fairness and common honesty are at the basis of most of its rules. Occasionally a new situation arises in which the law finds itself so hampered with the technicalities inherent in any definite system of jurisprudence as not to be able to deal as it would like with the new state of facts that have arisen. This is almost always because the state of facts is so radically new. It is one outside of the ordinary trend of the law. When such instances arise, the time for legislation has come.

52 But the courts have had no difficulty in the case of trade secrets. Recognizing the propriety of the proposition that they should be protected in cases where breach of confidence or breach of contract was involved, exact and well-defined principles with which the law was familiar led to intervention by the courts, to see that that was done which was right.

53 While such cases ordinarily are brought in Courts of Equity, because, as a rule, an injunction is sought, an action at law may be brought for damages.

Robb v. Green (1895), 2 Q. B. 315.

54 The injunction will run, not only against the employee, but a against those who, with knowledge of the confidential relations, have induced him to betray the secrets.

Morison v. Moat, 9 Hare 241.

Stone et al v. Goss et al, 65 N. J. Eq. 756.

Taylor Iron and Steel Co. v. Nicholas et al, 61 Atl. Rep. 946.

55 The vendee of the secret has the same right as the inventor of the secret and may bring a bill against a former employee of the vendor, who acquired the secret in confidence before the sale, provided the employee attempts to divulge the secret wrongfully.

Cincinnati Bell Fdry. Co., v. Dodds et al, 19 Weekly Law Bull. 84 (Super. Ct. Cin. O.)

56 The following are some of the cases in which the law as above stated has been enforced:

Plans of engine:

Merryweather v. Moore (1892), 2 Ch. 518.

Patterns of plaintiff's pumps:

Tabor v. Hoffman, 118 N. Y. 30.

Machinery for making gunny cloth by a secret process:

Peabody v. Norfolk, 98 Mass. 452.

Medicinal formulae:

Hartman v. Park & Sons Co., 145 Fed. Rep. 358.

C. F. Simmons Med. Co. v. Simmons, 81 Fed. Rep. 163.

Weston v. Hemmons, 2 Vict. Law Rep. 121 (1876).

Yovatt v. Winyard, 1 Jacob & Walker 394.

Morison v. Moat, 9 Hare, 241.

Green v. Folgam, 1 Sim. & St. 398.

Processes and formulae for manufacturing photographic supplies:

Eastman Co. v. Reichenbach et al, 20 N. Y. S. 110; 29 N. Y. S. 1143.

Process for making typewriter ribbons:

Little v. Gallus et al, 38 N. Y. S. 487.

Process for making sticky fly paper:

Thum Co. v. Tloczynski, 114 Mich. 149.

Secret process for making steel:

Taylor Iron and Steel Co. v. Nichols et al, 61 Atl. 946 (N. J. Eq. 195).

Secret process for detinning tin scrap:

Vulcan Detinning Co. v. American Can Co. et al, 67 N. J. Eq. 243.

Reversed on other grounds, 62 Atl. 881.

Secret process for the manufacture of compounds for removing hair and wool from hides:

Stone v. Goss et al, 65 N. J. Eq. 756.

Machine for making paper boxes:

Westervelt et al v. Nat. Paper and Supply Co., 154 Ind. 673.

Secret for dyeing cloth:

Bryson v. Whitehead, 1 Sim. & St. 74.

57 Many other trade secrets which are in their nature commercial, that is, business plans or devices, which were special to one who possessed them, and useful in his trade, have been in like manner protected by the courts. Examples of these are shown in the following cases:

News agency contract, by which the plaintiff sent news to its subscribers under contract not to divulge it is enforced in equity:

Exchange Tel. Co. v. Central News (1897), 2 Ch. 48.

Contracts of a commercial house must be kept secret by a clerk:

Hamlyn v. John Houston & Co. (1903) 1 K.B. 81.

See Salomon v. Hertz, 40 N. J. Eq. 400.

Forms and materials for printing advertisements in plaintiff's publication cannot be used by his agents for a rival publication:

Lamb v. Evans (1892), 3 Ch. 462. Aff'd (1893), 1 Ch. 218.

Confidential attorney's clerk enjoined from publishing extracts from books and papers of his employers or of their clients.

Evitt v. Price, 1 Sim. 483.

Although a law pupil has a right to retain copies of precedents in a barrister's or conveyancer's office, see

Merryweather v. Moore (1892), 2 Ch. 518, 525.

Order books containing customers' names cannot be copied by an employee to use later in his own business for soliciting orders:

Robb v. Green (1895), 2 Q.B. 315.

Tailor's assistant cannot take away patterns of clothes of employer's customers when he sets up for himself in order to induce those customers to resort to him:

Lamb v. Evans, (1892), 3 Ch. 462, at p. 468.

58 Analogous cases which throw light on the principle are the following:

One who makes copies of a drawing under contract cannot make extra copies to sell in competition:

Tuck & Sons v. Priester, 19 Q. B. D. 629.

See Levyeau v. Clement, 175 Mass. 376.

A photographer who takes a photograph to furnish customer with copies cannot sell or exhibit extra copies:

Pollard v. Photographic Co., 40 Ch. D. 345.

Moore v. Rugg, 44 Minn. 28.

See otherwise, Corliss v. Walker Co., 64 F. R. 280, where the customer is a public person.

59 Perhaps as comprehensive a statement of the general law as any is that of Mr. Justice Story in 2 Story's Equity, Sec. 952, as follows:

Courts of equity will restrain a party from making a disclosure of secrets communicated to him in the course of a confidential employment. And it matters not, in such cases whether the secrets are secrets of trade or secrets of title, or any other secrets of the party important to his interests.

60 The doctrine of these cases was first advanced something less than one hundred years ago. In two early cases Lord Chancellor Eldon refused relief. In one (Newbery v. James, 2 Merivale 446), because he did not see how he could pass upon the question without bringing out the secret in the court proceedings, in which case it would be disclosed and therefore cease to be a secret. The courts have been able to deal with this difficulty.

61 In the second case (Williams v. Williams, 3 Merivale 157), he refused relief, first because the defendant in his answer, denied that there was any secret, and, second, because he did not feel that the particular medicinal secret involved was of such a character as to entitle the plaintiff to the good offices of a court of equity.

62 In a third case, however (Yovatt v. Winyard, 1 Jacob and Walker 394), (1820), he granted the injunction asked, and the law has been practically settled since that time.

63 In some respects, the law of trade secrets does not seem quite complete. There have not been sufficient cases arising under sufficiently varying conditions to enable all aspects of the law to be worked out.

64 For example, under the decisions of the courts there seems to be practically no limit as to the character of the subject matter which may be treated and protected as trade secrets. They may be of small or large importance; they may or may not involve great novelty or real inventive quality. They may be mere business expedients which have a trade value because of their convenience, or because they record useful information. Unlike a patentable invention, it does not seem necessary that they should be "new" as well as useful.

65 One eminent judge has decided that a trade secret which had actually been described in an expired patent (there being no evidence that it had ever been practiced) was entitled to protection (Benton v. Ward, 59 Fed. Rep. 411–413). At first sight, it might seem that all that was required was that there should be a secret plan or method or device of any kind, to entitle its possessor to the limited protection which the law gives.

66 I doubt, however, if such is ultimately determined to be the law. When cases arise which require a close analysis of the question, it is probable that the courts will decide that there is something necessary over and above the mere question of secrecy to justify the

exercise of the power of the court to prevent the use or disclosure by one who acquired his knowledge in confidence or while under contract.

67 An employer may have a certain routine in dealing with his help, which he thinks aids him in his relations with them. He may give them certain favors that they appreciate. Can things like these be a trade secret which the law will protect? He may have discovered that a certain make of lathe or of sewing machine is better adapted to the work of his factory than any other. Can not an employee who leaves him, fairly take away that information and use it as part of his stock of trade? There must be some limitation to the things that can really be treated as trade secrets. Exactly as the courts have been forced to determine in special cases whether or not an alleged invention had patentable quality or was merely the result of the intelligent exercise of the skill of the art, so they will probably at some time determine that it is not everything which a man originates or acquires and uses for his own advantage, which is capable of becoming the sort of a trade secret which is entitled to protection. Just where the line will be drawn can not be forseen. It may be that a distinction will be made between those things that come into the art by a mere small dvelopment of old ideas and the exercise of ordinary trade knowledge and skill, and those that result from some degree of original thought, even if it is not of the grade which under the narrow terms of our statutes is required to constitute patentable inventions. It seems clear that as long as the present views of the courts prevail, many things will be protected as trade secrets which could never be the subject of letters patent.

68 Again, it does not seem as if a device or method or plan should be respected as a trade secret unless it is specific in its character and capable of exact description. It is not reasonable that vague general methods or indefinite, ill appreciated peculiarities of procedure should be dignified as capable of becoming in effect property.

69 The decisions have but little to say on such points. The issues in the decided cases have been too clear to make it necessary to develop them. Some time considerations like these will come up in special cases and the law will be started on a line of discrimination and distinction which will ultimately define the limitations, if any should exist.

70 Certain other propositions which are not very explicitly developed in the decisions of the courts or in the text-books, in my opinion are or ought to be a part of the law.

71 It is well settled that the alleged secret must be a real secret.

I believe, however, that before the courts should intervene to protect an alleged trade secret it should appear that it was not only regarded as a secret, but that it was distinctly treated and carefully guarded as such by the possessor of it. It should not be enough that he has had it in mind to call it a trade secret, if he ever needed to invoke the protection of the law. He must have taken all necessary and reasonable precautions to prevent its disclosure. Moreover, it does not seem proper that he should have redress against his employees and associates unless it is made to appear that they knew, while occupying the fiduciary relation which gave them the opportunity to learn the secret, that the specific thing now called a secret was in fact regarded and treated as a secret, which they must respect for all time. It should not be enough that one man has worked for another. The employee has a perfect right to grow with his experience. He has a right to carry away for general use everything that he learns in his place of employment, except trade secrets. The public interest requires this as much as it requires that trade secrets should be respected. The employee or associate should be notified of the exact trade secret, that he may know what results of his experience he can and what he cannot take away and use freely. Eternal vigilance and definite effort should be one price of the investment of a trade secret with any of the qualities of property.

72 With these qualifications, some of which are perhaps not yet fully elaborated in the opinions of the judges, there seems no reason to doubt that the law is thoroughly consistent with sound ethical principles. It is based on a view of what is for the interest of the community, which has commended itself to the judgment of mankind from the beginning. In its application, it insists only on loyalty and good faith, loyalty to one's employer and one's associate and to one's word, and the plain, good faith which is always expected where contract or fiduciary relations are established.

73 To test this question, let us suppose the law to be suddenly changed. I can conceive of only a few directions in which a change of any moment is possible. One would be to the effect that the possessor of a trade secret should publish it to the world so that all might have the advantage of it. Such a law would be incapable of enforcement, for the man who has a thought or an idea cannot be forced to express it. If the rule were established that one who practices his thought or his idea, thereby irrevocably gave it to the public, trade secrets would perhaps be eliminated to a large extent, and so would any progress in the art that is based upon them, for the possessors of them would have none of the stimulus to develop them into practical form and

make them useful and profitable, that is based upon the chance of monopolizing them. Surely, this would result in no benefit to the community.

74 Again, the law might be modified so as to remove the present restrictions against the disclosure of a trade secret by one who thereby is guilty of a breach of trust or of contract. So long as we maintain our present standards of right and wrong, so long as we value and insist upon loyalty and good faith, would not such a change in the law be inconsistent with all that is good in human nature, and the application of a principle which is most distinctly immoral? If an employee or trusted associate, for selfish ends, can be disloyal in the matter of a trade secret known to him as such, and the knowledge of which he would never have acquired except through his relation to the possessor of the secret, why should he be loyal in any other matter? It is conceivable that disloyalty as to a trade secret might be the most serious conceivable blow to the one who had given confidence, expecting honesty and fair dealing in return. I trust that the day will never come when the courts will find it necessary to modify in this way a principle of law which to so great an extent emphasizes good faith, which depends so much upon a recognition of the obligation to keep agreements, which is founded upon a sound public sentiment and the underlying virtues of loyalty and fair dealing.

75 It is somewhat surprising that apparently there is no reported case in which an effort has been made to invoke the aid of the courts to protect a trade secret which has been stolen by an outsider. It probably has happened many times that a formula has been copied or a secret found out by one who was not in confidential relations with the possessor of the secret but who got the information surreptitiously. It is quite conceivable that a mere trespasser or a thief should discover such a secret. If such instances were to arise, it seems to me not improbable that the law would interfere to prevent the disclosure of the secret by the one who stole it and its use by any to whom the thief disclosed it. It could not do so, however, on the ground of breach of confidence or breach of contract. The courts would have to base their intervention on some other ground consistent with the general principles of law.

76 In the case of Yovatt v. Winyard, to which I have already referred, a formula had been copied surreptitiously, but it was by one having contract relations with the possessor of the secret.

77 Speculation as to how the courts would deal with such cases is not relevant to the general subject of this paper.

78 Believing as I do that the law of trade secrets is fundamentally

right and in accord with sound ethical and social principles, at least as gaged by our present standards, I have not turned aside to consider the possible objection to the views that have prevailed. It seems to me that those objections are largely based upon a consideration of the obvious hardships involved in the situation. It is a burden that one who knows a useful thing should not have full power to utilize it. Is not this true of every legal restriction upon the individual? It is often a serious matter for one to carry out a contract. From a narrow and material point of view, it is frequently disadvantageous to keep faith and respect confidence. Every property right implies that something is monopolized by one or by a few that many others would like to have. The hardship in not being able to utilize knowledge of a trade secret, obtained by way of confidence or contract, express or implied, is not different from that resulting from a multitude of other obligations that are constantly arising, some from our voluntary acts and others from the restrictive operation of laws and usage that have been developed for the common good and which are forced upon all of us whether we like it or not.

79 It must not be forgotten that no man need place himself under the embarrassment of knowing a trade secret unless he chooses. Each of us is free to refuse the employment or the relationship or the contract from which such knowledge would come. If we do not refuse, we must, as in all other relations in life, accept the situation as a whole, with its burdens as well as its advantages. There is nothing special as to trade secrets in this regard.

80 Neither must it be forgotten that the right to protection in the use of a trade secret is a general right. It is sometimes suggested that while the rules of law, as I have defined them, were adapted to a former condition of things, they are not in harmony with our present industrial situation. I do not think that such is the case.

81 It is true that in the early years of the last century, when the trade secret of today, in its legal relations, was formulated by the courts as a logical development of the general principles of law, the units of trade were small. Trade secrets were then in the possession of small manufacturers, for there were no large ones. They were often heir-looms, passing from father to son, for generations. We all know how conditions have changed. In so far as trade secrets play any part in our industries of today, they are necessarily, to a large extent, features of our modern corporation and factory system, although there are still many secrets in the possession of individuals who use them for their own advantage, sometimes selling the knowledge of them to several concerns, always under a pledge of secrecy which the

courts would enforce. I do not see how these changes in industrial conditions affect the question under discussion. The reasons which led to the original protection of such secrets against breach of contract or breach of faith one hundred years ago, are sound today. If such protection was fair and reasonable then, it is fair and reasonable now. If it was then in the public interest as leading to the promotion of the useful arts, the same is true today. If such secrets were entitled to recognition in the last century, it was because their existence and support were in harmony with public sentiment. Unless that public sentiment has changed, they are still in harmony with it. I do not believe that it has changed.

82 The law on the subject is the same whether the secret is of large or small importance, whether it is possessed by an individual or a corporation. We should not forget that any one of us in this room, and any workman in any factory in the land, may light upon such a secret. If he does, it will have the protection of the law. It may be used by the one who possesses it, or he may by contract determine the manner and extent of its use. In any case he will have control of it as a reward for his intelligence or forethought in coming into possession of it. He will have encouragement to put it in use, in which case the public will get a benefit from it which they might otherwise never have received.

83 A consideration of possibly more moment is that there is offered to the originator of certain special forms of industrial secrets, or to his assignee, the protection afforded by the grant of letters patent. It may be contended that the opportunity to patent an invention is all the encouragement to the promotion of the useful arts that is required in the public interest, and that there should be no other reward for the origination of a new thought or of a new method or device than that given by a patent. Passing for a moment the point that only a small class of useful ideas are capable of receiving the benefit of letters patent and referring only to things that are patentable, such a view does not seem to me fair or reasonable. Why should a man be forced, against his will, to publish what is in his mind? Ought he not to be allowed to determine for himself what is for his interest? Should he not be free to decide whether he is likely to get an adequate reward, under the patent act, if he does make the publication? If he concludes that such will probably not be the case, should he not be at liberty to use his new idea as a secret in his business, or in some business with which he establishes relations, taking his chances as to the secret being discovered?

84 The whole law of patents implies the right of a man to keep as

a secret that industrial improvement which he has conceived. It is because that right is recognized that patent laws exist. They say in effect: "You, the inventor, have a trade secret which is, among other things, new, useful and the result of invention. You may keep this secret if you can, and so long as it is kept secret you and those claiming under you alone may use it. If your secret is discovered without breach of faith, as may be the case at any moment, you lose it absolutely. Do you not prefer to make a contract under the patent law by the terms of which you are to publish your invention in the best form known to you, and in consideration of that publication secure a right, which you cannot otherwise have, and which shall be enforceable by law, to prevent the use of your new idea by any others without your consent for a limited term, say seventeen years? You will, to be sure, sacrifice the chance you now have of keeping your invention for an indefinite time a secret and therefore in your own control, but in return you get the right to invoke the aid of the law to restrain any use without your consent for a certain period. Which course do you think most for your advantage?"

85 If all trade secrets could be patented, and if the patent law was as satisfactory in substance and in administration as we wish it might be, there can be no question which course would be the most advantageous to the one who possessed the secret. A patent would be enormously more satisfactory than the chance of preserving a trade secret. The latter, at the best, is a most uncertain and insecure property. It may be lost so as to be open for use by any one, in innumerable ways which are not within the scope of the rules of law to which I have referred. It may be disclosed by accident by the one who possesses it, or unintentionally in such a way as to involve no breach of faith by those who know it.

86 As I understand the decisions, even unfairness or want of faith on the part of one who receives knowledge of the secret in confidence, does not make it impossible for him, before he is enjoined by the courts, to disseminate the information so that those who get it from him may use it freely. A person who has notice of the incapacity of his informant to violate confidence, or one who has given no consideration for the information, would be subject to injunction. On the other hand, a *bona fide* purchaser of the secret who had no notice of any beach of confidence or of contract on the part of the one who sold him the information for value, could, I believe, use the information without interference from the courts. He, as a *bona fide* purchaser for value and without notice would have an equity equal to that of the possessor of the secret. Under such circumstances the courts are not likely to interfere.

87 If a disclosure was wrongfully made in trade journals or otherwise, it would be a difficult, almost an impossible task for the one whose rights had been violated to secure redress against the entire public who had read of the secret and who were actually innocent of any breach of faith. Moreover, where there is a trade secret, the fact that it exists is likely to be known throughout the trade, and each competitor has the full right to find the secret for himself, using all information as to its nature and the results from it that he can get from an inspection of the product, from speculation, or in any fair way. I will say nothing as to unfair ways that might be employed and which might be carried out with effect, but so shrewdly as to evade the law. No man would prefer a trade secret to a patent if the only question was one between the chance of keeping his device or method to himself indefinitely without publication, and publication with a reasonable certainty of protection during a limited term. But the issue does not come up in this simple fashion.

88 In the first place, as is shown by the cases I have cited, many trade secrets are not of a patentable character. It may be that the number of these will be reduced as the law develops. Many such should surely be capable of protection in some way. There is no other possible way than through the present rules of law to which I have referred. Most of these unpatentable ideas are of relatively small importance.

89 Of the valuable trade secrets such as new mechanical or chemical processes, some undoubtedly have or once had patentable quality.

90 Should the taking of a patent be the only possible protection for these? I think not.

91 There are many valid reasons why the discoverer of a new industrial process may well determine not merely that it is for his interest to take his chances of keeping it secret rather than to publish it in a patent, but that the latter course might lead to disaster. While it is generally but not always easy to prove an act of infringement of a patent on a product, or a tool or a machine in general use it is often practically impossible to obtain legal proof of the process employed by one who is believed to infringe a process patent. The infringer is very apt to be able to keep his infringement an undiscoverable secret. I am inclined to the belief that a substantial part of the important and valuable trade secrets now in use, most of which are processes, would if patented be used without much if any chance of redress on the part of the patent owner. At any rate, if the one who controls the secret fears that he could not prove infringement of a patent, is it contrary to public policy that he should be allowed to take his chances of

keeping what he has discovered a trade secret rather than run the risk of losing it altogether by publishing it?

92 Again, nothing can be patented unless it involves invention. Pages have been written by way of defining invention. Many of our greatest judges have given all possible thought to the subject. It is still indefinite, however. The judgment of the Patent Office on the point is every day overruled by the courts. No lawyer can advise any confidence in a great number of the cases that come before him.

93 Inasmuch as a trade secret is a man's own, to use or not as he pleases, can it be required that he should absolutely give up his opportunity to utilize his idea for his own benefit, and incidentally for the benefit of the public, in his own factory and under the seal of secrecy, and take a patent which might be declared invalid for want of invention, no matter how useful and meritorious the subject matter might be? In like manner, when one takes a patent, he exposes himself to the danger of having it declared invalid on any of an innumerable number of other grounds which he cannot foresee or guard against. If he prefers to keep what he has a secret, if he can, is there any substantial ground why he should not be allowed to do so?

94 Moreover, admirable and effective as is our patent law, there are involved in its administration many difficulties other than that of proving infringement. In practice it is most cumbersome and expensive. Years are likely to elapse before a test case can be determined, during which infringement becomes general. Under our present court organization, with no single appellate tribunal covering the whole country, a victory for the patentee in the first case does not settle the situation. He may have to sue many infringers in many parts of the land before his rights are generally recognized.

95 Our patent system is probably the best in the world, and it is certainly administered by courts of great intelligence and high character. The difficulties to which I have referred, and other like difficulties, are inherent in any patent system. Certainly it would require strong considerations of public policy to force an inventor to take what is offered by the patent law as his only form of reward when he may see clearly that the new thing which he has may not stand the strain of patent litigation, but may be profitable to him, and useful to the community if he can keep it for a reasonable time as a trade secret.

96 It is to me somewhat significant that the legislatures of England and America which have many times dealt with the patent law have never directly touched the subject of trade secrets. They seem to have recognized the fairness and justice of the common law rules on

the subject, and that the only course which would commend itself to a sound public sentiment was to make the patent laws so attractive as to induce the owners of patentable trade secrets to publish them in consideration of the patent grant. In this they have to a large extent succeeded. The number of patents is very great, while the number of trade secrets is very small. It is only in a few special classes of subject matter that the patent is not a more attractive reward for the new contribution to industrial progress than is the limited protection given by the law to a trade secret. There are few situations in which the secret can be kept at all, even if everyone exercises the utmost possible good faith. It is impossible in the case of a product, whether chemical or mechanical, and more than difficult in the case of tools and machinery. It is only with processes which are practiced in a factory and which are not disclosed by a study of the product that there is any substantial chance of maintaining secrecy. To a far less extent, tools and machines which are not generally distributed have some chance of being kept secret.

97 If a man elects in those few cases not to publish but to take his chances, can there be any real objection to his pursuing that course? It is certainly inconvenient and annoying to some extent. It is a real personal hardship that a workman or engineer who has learned the secret under such conditions that he must respect it, can not utilize it in his subsequent work. It undoubtedly holds back the progress of the useful arts to some extent that the whole world is not free to practice it and to improve upon it. But this, in theory, is equally true as to things that are patented, during the long term of seventeen years in which no improvement on the thing patented can be rightfully used except by the patentee or those claiming under him. It would be true of any monopoly given the inventor or devisor of a new thing as a reward. But the progress of the useful arts is, I believe, enormously promoted by the patent system. I doubt if it is interferred with to any appreciable extent by the requirement of good faith in those who have in confidence become acquainted with trade secrets.

98 On the other hand, I believe that sound business generally and the comparatively few arts in which such secrets are of any importance are definitely promoted by the fact that the law aids in preventing disclosures based upon bad faith.

99 I have referred to the analogy between trade secrets and patent rights, on the one hand, and the privileges of copyright on the other. The analogy is significant as showing the logic of the law, and the basis upon which it has been developed.

100 The copyright which protects a publication of any kind is purely statutory, exactly as is the protection given by letters patent. It is an inducement to publish, that is, to give to the world what might otherwise never be published. As in the case of a patent, it secures to the owner a monopoly for the thing published for a limited term, after which the field is open to everyone. It is distinct recognition of the author's right not to publish unless he chooses.

101 But in addition to the statutory copyright, there is a common law copyright which does not deal with publications at all. This protects the unpublished book, or piece of music, or play, or picture, and even the letters which one writes, against publication or exhibition by others than the person who originated them or secured the lawful control of them as unpublished material. The protection is the same as that in the case of a trade secret. The right of the owner to publish or not, as he pleases, is recognized as absolute. He may make what private use of the unpublished material he chooses. He loses all common law protection if and when he publishes. Up to that time those whom he takes into his confidence must respect his sole and exclusive control of the unpublished matter. They can not publish it nor can they use it without his consent. It is obvious how close this branch of copyright law is to that governing trade secrets.

102 This is only another illustration of an application of the principles for which the courts have contended in the development of the law as to trade secrets. In both cases the authorities are substantially a unit, and their views seems supported by public opinion and consistent with sound business policy.

103 Such are my views as to the ethics of trade secrets. They are those of the courts, and I believe of the public. I recognize that all industrial questions are now under investigation. Much good will comes from a fresh study of them in their relations to modern social, political, and economic conditions. There is no class of men in our land more capable of coming to sound conclusions on such subjects than that represented by the Society which I now have the honor of addressing. There are no men whose influence is greater.

104 The question we have been considering is only one of many upon which the community has had settled views which were reflected in the unanimous findings of the courts. As to some of those questions, it may be that we are on the verge of marked changes of thought which may result in equally great modifications of what have seemed to be sound and permanent industrial and business principles, and in the applications of those principles. The engineers of the United States will surely be on the right side of the discussion of these sub-

jects, and of any political or judicial action which follows those discussions. It may be well in every case to consider the grounds for the doctrine that has prevailed before condemning it altogether. It will always be necessary to determine whether the criticism should not be directed to the applications of the doctrine; that is, to the special cases, rather than to the doctrine itself. In the matter of the trade secret, there may be hardship or even wrong in special cases. If so, let us find out how to deal with the subject so as to retain what is right and to eliminate what is wrong. A modification of the present rules of law may perhaps be essential to that end.

105 The important thing for us to determine is whether or not the prevailing views as exemplified in the decisions of the courts, are not fundamentally sound, based as they purport to be on principles of thought and action that are in harmony with elementary rules of public policy and good morals. If they are right they should be sustained. For myself, and speaking generally, I can not see what fairer or more reasonable views could be advanced in their stead.

No. 1138

THE TESTING OF INFLAMMABLE GASES

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Member of the Society

With the increasing demand for internal combustion engines, the great activity in by-product and producer plants, and the vigorous growth of gas industries, the testing of gases for their calorific value and foreign ingredients is one of the duties of the engineer, and a simple, quick, and efficient method of making such determinations greatly facilitates his work.

2 In making efficiency tests of gas engines and in determining the solid matter, moisture, and calorific value of gases, methods have been used and apparatus designed by the writer which give uniform and rational results heretofore obtained through more tedious operations.

3 In order to determine the heating value of a gas it is necessary to utilize all the heat of combustion in doing tangible work which can be measured without error or loss. The heat of combustion of a measured quantity of gas is used to raise the temperature of water; and the quantity of water, the rise in temperature, and the volume of gas are the three factors necessary to get its calorific value.

4 In order to prevent a possible error through radiation, the temperature of the gas, surrounding air, inlet water, and exhaust products, should be practically the same; then if the loss of heat by radiation from the water whose temperature is rising is obviated, reasonable results are possible.

5 Junker and other similar calorimeters give excellent results with skilled operators, but the accuracy of the data obtained from them depends largely on the personal equation of the operator. In the apparatus used by the writer greater simplicity of manipulation has been obtained by making the instruments as nearly automatic as possible. Temperatures are read in degrees fahrenheit instead of centigrade and the outlet of water is weighed instead of being measured, making it possible to read directly B.t.u. without previous transforma-

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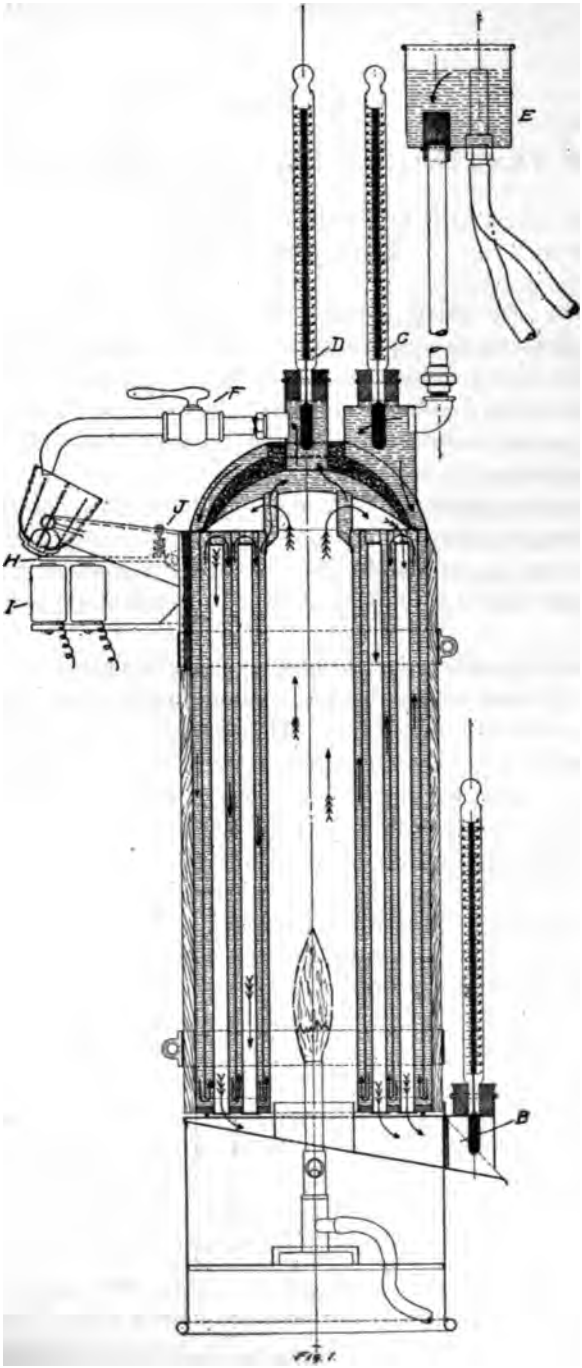

FIG. 1 DETAIL OF SARGENT GAS CALORIMETER

tion. When the needle of the meter passes the zero point the water being weighed is automatically switched from the full to the empty receptacle designed to receive it. By these means one operator can get more uniform results and get them oftener, than two operators working in the old way.

6 In the apparatus used by the writer, the inlet water, the temperature of which should be practically that of the surrounding air, envelops the whole calorimeter, thereby carrying in the heat which it might absorb from the water whose temperature is rising.

7 Fig. 1 shows a section of a calorimeter in which the inlet water, having a constant head at the cistern *E*, the temperature of which is taken at *C*, envelops the whole instrument and passes through in the direction of the arrows ⟶, and the rise in temperature is taken by the thermometer at *D* before any heat is lost by radiation to the air. The combustion of gas takes place in the central flue and the products of combustion pass to the top and down the annular chambers in the direction of the arrows ➵, reaching the temperature of the water before passing out at *B*, where a damper regulates the velocity and the thermometer gives the temperature of the exhaust products.

8 The calorimeter should be operated in a closed room free from air currents which disturb the equilibrium and vitiate results. Even with the most perfect conditions, errors from observation or conversion are possible. When British thermal units are desired, as is the case in most English speaking countries, and centigrade thermometers are used, mistakes are sometimes made in transformation. As a degree fahrenheit is $\frac{5}{9}$ of a degree centigrade, when both are divided into tenths, the fahrenheit thermometer will give nearly twice as close a reading as the centigrade instrument.

9 When the outlet water is measured in graduated beakers, it must be changed from cu.cm. to pounds. The varying meniscus, the possibility of the beakers being out of level, and the temperature of the water are elements of error possible when the outlet water is measured. By weighing the discharged water and using fahrenheit thermometers, no transformation from cu. cm. to grams, from centigrade to fahrenheit, or from calories to B.t.u. are necessary, Readings are direct in B.t.u. and errors of transformation and the mysteries of metric measurements are entirely eliminated.

10 One of the greatest errors in determining the calorific value of a gas arises when the operator attempts to switch the outlet water from one receptacle to another after a certain quantity of gas has been burned. To eliminate this "personal error" the automatic dumping bucket, shown in Fig. 1 and 2, was designed. This bucket is held in

position by the keeper *H* and spring *J*. The weight of the water on the full side tends to oscillate the bucket so that the water will flow into the empty side and through another outlet to the empty receptacle. When the test meter needle passes the zero point (behind the binding post, Fig. 2) an electrical circuit is completed, which, passing through the solenoid, Fig. 1, draws down the keeper *H* and allows the outlet water to change automatically from the full to the empty pail, Fig. 2.

FIG. 2 EXTERIOR VIEW SARGENT GAS CALORIMETER

11 With such a device the personal error is not only eliminated but much of the work of the operator is done automatically, thereby allowing him more time for observing the temperatures and weighing the water delivered. By switching the water for every tenth of a cubic foot of gas burned, observations are taken about every four minutes and the calorific value can be determined for the preceding test before the meter needle completes its next rotation. In this way a test may continue without intermission as long as the engine is in operation, or the producer is furnishing gas.

12 Since the calorific value may vary in illuminating gases

during the conditions of manufacture, in producer gas with varying feed and output, and in natural gases, coming from different wells, which are often mixed with illuminating or water gas to keep up the pressure when the demand in large cities during zero weather exceeds the supply, short runs but continuous determinations are necessary for satisfactory and rational results.

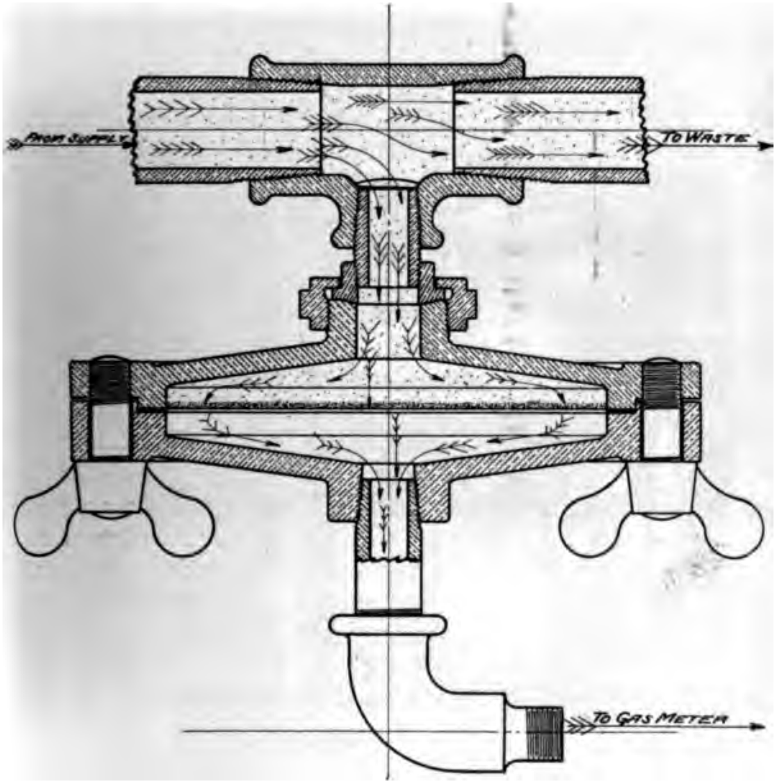

FIG. 3 DETAIL OF FLOW OF GAS IN SARGENT DUST DETERMINATOR

13 If the thermal efficiency of an engine is desired, the calorific value of the meter gas only is necessary, but for the sake of comparison, the British thermal units are usually given in cubic feet of standard gas. The book of tables compiled by Professor McFarland, Member of the Society, enables the operator to change meter gas to standard gas, merely by knowing the temperature, pressure, and barometer readings. With fahrenheit thermometers, scales weighing to hundredths of a pound, tables reducing meter gas to standard gas,

and automatic devices not only to do a great deal of the operator's work but to eliminate the error which necessarily arises under hand manipulation, the determination of the heat units of any gas by the calorimeter becomes a simple matter.

14 In testing producer gas below atmospheric pressure it is usual to raise the pressure with a water ejector, but as this may add

FIG. 4 EXTERIOR VIEW OF DUST DETERMINATOR

more or less water to the gas, the pressure is preferably raised with an electric or hydraulic driven centrifugal fan, as no moisture is added to the gas by this method.

15 When testing gas that has been washed and dried to determine the efficiency of the drier, the gas is passed through a condenser to reduce its temperature, or through calcium chlorid bottles to absorb the

moisture, or through both, as the conditions demand. By weighing the bottles and the calcium before and after and knowing the cubic feet of gas, the percentage of moisture is readily obtained.

16 When the efficiency of the gas washers is required, *i.e.*, the grains of dust per cubic foot in the washed gas, at the same time the calorific value is determined, the gas is passed through a filter paper, the holder of which is shown in section in Fig. 3, which retains every particle of dust, as is proved by letting the gas pass through two filter papers in series, the second of which remains white and does not increase in weight.

17 When gas is tested for dust and moisture only, a self-contained outfit, Fig. 4, provides for continuous determinations. The gas passes through a filter, condenser, calcium chlorid bottles, and test meter, and while the accumulations of dust on one filter paper are being weighed, gas is passing through the other. In this way a continuous record of the dust in blast furnace gas is obtained and the efficiencies of the working apparatus maintained.

18 The calorimeter complete, as used by the author, consists (Fig. 2) of a test meter, which reads in cubic feet—one revolution of the pointer of which measures 1/10 of a cubic foot—gas thermometer, pressure gage, one pressure regulator with micrometer adjustment, one Bunsen burner, and one calorimeter proper with inlet, outlet, and exhaust products thermometers graduated in tenth of degrees fahrenheit, automatic dumping bucket, dry batteries, balanced copper pails, and decimal platform scales. When gas is tested for solid matter at the same time its calorific value is determined, the tar, moisture, and dust extractors as shown on the right are used.

19 As the products of combustion are saturated, the gas and air should be saturated if the net amount of hydrogen in the gas is desired.

20 In determining the calorific value of metered gas, no corrections for pressure and temperature are made and the results would be recorded as follows:

LOG

DATE, AUG. 14, 1906. KIND OF GAS, NATURAL, FOR K. C., B. & N. CO. AT K. C., MO.

TIME	TEMPERATURE DEG. FAHR.						CU. FT.	LBS.	B. T. U.
P.M.	H_2O-IN	H_2O-OUT	DIF.	GAS	AIR	EXHAUST	GAS	WATER	
1:30	62.5	72.	9.5	62	62	62.1	.1	8.91	846.45
1:34	62.5	72.	9.5	62	62	62.0	.1	8.93	848.35
1:38	62.6	72.1	9.5	62	62	62.1	.1	8.90	845.5
Average	62.533	72.033	9.5	62	62	62.06	.1	8.913	846.76

21 In this case 1/10 of a cubic foot of gas is burned every four minutes and the B.t.u. are determined for every tenth of a foot consumed.

In like manner the log may be continued indefinitely or as long as an engine test may last.

22 As the temperature of the gas, air, and exhaust products should be practically constant and as these temperatures are not used in the calculations, a record for each reading is seldom taken. Often these temperatures are noted only under remarks or at the beginning of the log, which simplifies the work and allows room for reducing the metered gas to standard gas during the observations. When such results are desired the log would be as follows:

DATE............GAS..........FOR....................AT..........................

	TEMPERATURE DEG. FAHR.			PRESSURES	
	ROOM	GAS	EXHAUST	BAROMETER	GAS
START	60	60	61	28.854	.5
FINISH	61	60	60	28.854	.5

TIME	H_2O-IN	H_2O-OUT	DIF.	LBS. WATER	CU. FT. GAS METERED	CU. FT. GAS STANDARD	B. T. U. PER CU. FT. METERED	B. T. U. PER CU. FT. STANDARD
3.25	60.5	69.8	9.3	9.5	.1	.09704	883.5	910.4
3.28	60.5	69.9	9.4	9.5	.1	.09704	893.0	920.2
3.32	60.5	69.9	9.4	9.48	.1	.09704	891.1	918.3
Average	60.5	69.86	9.36	9.49	.1	.09704	889.0	916.3

23 From the barometer readings, 28.854 in the above log, we add 0.037, the pressure of ½" water in mercury, making the absolute pressure of the gas, 28.9 and, from the tables above referred to for gas at 30 in. of mercury and 62 degrees fahr., we find the constant to be 0.9704, which, divided into the B.t.u. of metered gas, gives the B.t.u. of standard gas.

24 The B.t.u. obtained are the total or high value of the gas. As the exhaust products of a gas engine are hotter than boiling water and the products of combustion of the hydrogen and oxygen are in the form of steam, the latent heat of the steam in the products of combustion must be subtracted from the total B.t.u. to get the low or available value.

25 As the latent heat of steam is 966.6 B.t.u. per pound and as the condensed water, which is cooled down to the temperature of the exhaust products, absorbs this additional amount of heat, the available heat in the gas equals the difference between the high value and the B.t.u. represented by the pounds of steam condensed times the latent heat of steam plus the difference between 212 deg. and the temperature of the exhaust products.

26 As soon as the dripping of the water coming out with the products of combustion is uniform, the test for the low value can be started and run while the high value is being obtained. From one to

three feet of gas are burned before condensed water is weighed and the difference between the high and low value is ascertained.

27 If during these determinations of the heating value of a gas showing an average of 960 B.t.u. per cubic foot, three cubic feet of gas are burned and there is collected 0.15 pound of water, and the temperature of the exhaust gases is 60 degrees fahr., the hydrogen products would be

$$\frac{(966.6 + (212 - 60)\ 152 \times .15}{3} = 55.9 \text{ B.t.u.}$$

which subtracted from the high value (960 − 55.9) gives 904.1 B.t.u., the available heat in the gas when used in an engine whose exhaust is hotter than 212 degrees fahr.

28 The percentage of dust per cubic foot is determined as follows: The filter paper is dried and weighed and after several feet of gas have passed through, it is again dried and weighed and the grains per cubic foot are determined.

29 In conclusion, the author finds that the analysis of gases for their B.t.u., dust, and moisture is greatly facilitated,

a By enveloping the water whose temperature is rising with the inlet water to prevent radiation.

b By using fahrenheit thermometers graduated in tenth degrees.

c By making frequent but continuous determinations when testing gases whose calorific value varies.

d By having the water automatically switched from one receptacle to another when a tenth of a foot of gas is burned.

e By weighing the heated water on decimal scales in balanced buckets rather than measuring it in graduated beakers.

f By using filter papers to strain out the dust in preference to cotton filled tubes.

No. 1139

DEDICATORY EXERCISES OF THE ENGINEERING SOCIETIES BUILDING

PROGRAM

First Day, Tuesday, April 16, 1907

Dedicatory Exercises

At 8 P. M.

Music. Largo, Händel. The Richard Arnold Double Sextette.

Opening by Charles Wallace Hunt, Past President A. S. M. E., Presiding Officer. The first use as a gavel of the setting maul employed by Mrs. Carnegie in laying the corner stone of the building.

Prayer by Rev. Edward Everett Hale, D.D., Chaplain U. S. Senate.

Communications from The President of the United States; The President of the Republic of Mexico; The Governor General of Canada.

Historical Address by Charles F. Scott, Chairman of the Building Committee.

Acceptance of the Building by E. E. Olcott, President of the United Engineering Society, representing The Founder Societies.

Address by Andrew Carnegie, Donor of the Building.

Music. Traumerei, Schumann. Cello Solo, Kronold

Oration by Arthur T. Hadley, President of Yale University, "The Professional Ideals of the Twentieth Century."

Music. Hallelujah Chorus, Händel.

Formal Dedication of Building

Adjournment.

Reception

9:00 P. M TO 10:30 P. M.—General Reception in the Main Auditorium.
10:00 P. M.—Reception by the Officers and Councils of the Founder Societies in their respective Headquarters.
American Institute of Mining Engineers—Ninth floor
American Institute of Electrical Engineers—Tenth floor
The American Society of Mechanical Engineers—Eleventh floor

Refreshments were served during the evening on the fifth floor.
Music in Main Auditorium, Fifth and Library floors.

Second Day, Wednesday, April 17, 1907

Dedicatory Exercises

At 2.30 P. M.

Introduction by John W. Lieb, Jr., Chairman of Dedication Committee.

Addresses by Presidents of Founder Societies:
Samuel Sheldon, President, American Institute of Electrical Engineers.
F. R. Hutton, President, The American Society of Mechanical Engineers.
John Hays Hammond, President, American Institute of Mining Engineers.
T. C. Martin, President, The Engineers' Club.

Greetings and Felicitations from Foreign and National Scientific Societies and Institutions of Learning.

Address by James Douglas, Past President, American Institute of Mining Engineers.

Presentation of the John Fritz Gold Medal to Alexander Graham Bell, Past President, American Institute of Electrical Engineers. (By Charles F. Scott, Chairman, John Fritz Medal Board of Award.)

Presentation of Commemorative Medals for Distinguished Services to R. W. Pope, Secretary, A. I. E. E.; F. R. Hutton, Past Secretary, A. S. M. E.; Rossiter W. Raymond, Secretary, A. I. M. E. (By A. R. Ledoux, Past President, A. I. M. E., representing the three Societies.)

PROFESSIONAL SESSIONS OF FOUNDER SOCIETIES

Monday, April 15, 8.15 P. M.

Special meeting of the American Institute of Electrical Engineers in Main Auditorium presided over by Sir W. H. Preece, K. C. B., F. R. S., Past President and Representative of the Institution of Electrical Engineers of Great Britain.

Paper by Louis M. Potts on the Rowland Telegraphic System and its Apparatus.

Thursday, April 18, 2 P. M.

Meeting of the American Institute of Mining Engineers in the Main Auditorium. Illustrated paper by H. T. Hildage on Mining Engineering Operations in New York City and vicinity, descriptive of the excavation and tunnel work now in progress in Greater New York.

Thursday, April 18, 8 P. M.

Meeting of The American Society of Mechanical Engineers in the Main Auditorium. Paper by Brig. Gen. W. Crozier, U. S. A., on "The Ordnance Department as an Engineering Organization."

Friday, April 19, 8 P. M.

Informal Smoker and Vaudeville, Madison Square Garden Concert Hall, under the management of the American Institute of Mining Engineers for the members of the three Founder Societies.

All engineers visiting or residing in New York were cordially invited to participate in the special exercises of the Founder Societies during Dedication Week.

Full programs were issued by each Society as to its special functions of the week.

ACCOUNT OF THE DEDICATION OF THE ENGINEERING SOCIETIES BUILDING[1]

The Dedicatory Exercises of the Engineering Societies Building were held on Tuesday and Wednesday, April 16 and 17, 1907.

The opening exercises were presided over by Charles Wallace Hunt, Past President of this Society and a Trustee of the United Engineering Society. In calling the meeting to order, he employed for the first time as a gavel the setting maul which Mrs. Andrew Carnegie used upon the occasion of the laying of the corner stone of the Engineering Societies Building. He called attention to her gracious act which placed the implement in the hands of the Engineering Societies to be used thenceforth by the presiding officers at the meetings held in the auditorium.

The opening remarks of Mr. Hunt were followed by a prayer offered by the Rev. Edward Everett Hale, D.D., Chaplain of the United States Senate, closing with the Lord's Prayer, in which the audience joined.

Congratulatory messages were read from the President of the United States, the President of the Republic of Mexico, The Governor-General of Canada, Der Verein deutscher Ingenieure, La Société Belge des Électriciens, The Society of Marine Architects, Berlin; The Royal Office for Examining Materials, Berlin; Verein zur Beförderung des Gewerbfleisses, Associazione Elettrotecnica Italiana, Milan; The Royal Academy of the Lincei, Rome; The Board of the Koninklijk Instituut von Ingenieurs, Gravenhage; The Colorado Scientific Society; The Western Association of Technical Chemists and Metallurgists; The Society of Beaux Arts Architects; Columbia University; The Thomas S. Clarkson Memorial School of Technology; The Smithsonian Institution; The University of Pennsylvania; The State University and School of Mines of North Dakota; Stevens Institute of Technology and the University of Michigan.

[1] This account of the Dedication of the Engineering Societies Building is merely an abstract. The complete record of the event was published in Proceedings, vol. 28, no. 9 and 10, and will appear in the Dedication Memorial Volume to be published by the United Engineering Society.

Several messages were received from individuals, among whom were, Lord Kelvin, Mr. Charles Haynes Haswell, Mr. Emil Swenson, Director of the American Society of Civil Engineers, Sig. Ing. Guido Semenza, Sig. Prof. Guiseppe Colombo, *Senatore del Regno*, MM. H. LeChatelier, Victor Belugou, *Principal Engineer of Posts and Telegraphs*, Paris, France; Sir James Kitson and Sig. Ing. Spagnoletti.

Mr. Hunt gave an interesting sketch of the first efforts to secure funds for a building. The germ of the idea was contained in an address made by Charles F. Scott, then President of the American Institute of Electrical Engineers, in which he voiced the hopes of the progressive engineers who had so long worked in various ways toward a common end: he drew a word picture of a building, the "Capitol of American Engineering," which should contain assembly halls and a great technical library, and be the abode of the national and all Engineering Societies. The keynote of this address and of the addresses at the dinner known as the Library Dinner given by the American Institute of Electrical Engineers, at which Mr. Carnegie was the guest of honor, was coöperative work among the Engineering Societies.

CHARLES F. SCOTT

The address by Charles F. Scott, Chairman of the Joint Conference and Building Committee, dealt with the history of Mr. Carnegie's gift from the informal meeting of Messrs. John Fritz, John C. Kafer, William A. Redding, Calvin W. Rice, Charles F. Scott and John Thomson for the discussion of the project with Mr. Carnegie, to the completion of the building.

On February 14, 1903, Mr. Carnegie stated he would give one million dollars for the erection of a building for the Engineering Societies and The Engineers' Club, designating as the direct recipients of the gift, the American Institute of Mining Engineers, The American Society of Mechanical Engineers, the American Institute of Electrical Engineers and The Engineers' Club. At a later date he generously increased the gift to one and a half million.

Mr. Scott further sketched the difficulties which confronted the Committee; first in designing a building for which there existed no precedent, and in making that design meet, to the largest advantage, the professional as well as the social needs of the Societies, keeping before them always the ideal which Mr. Carnegie had in mind in bestowing the magnificent gift—that "coöperation is the keynote of success and the harmonizing feature which counts for everything in the progress of any great movement, political, social or scientific."

Mr. Scott said that engineering societies are the expression of engineering forces, and engineering forces are fundamental to the achievements of our age. The engineer has been foremost in bringing about our present civilization, and to him new and larger problems are continually presented. These increasing responsibilities demand that the most efficient methods be found through the interchange of knowledge and experience. The engineering society has become the clearing house for knowledge and experience, and herein is the great purpose of this building, the significance of which is not in the past, nor in the present, but in the future; and the work we here inaugurate is the beginning of a new era in engineering.

CHARLES WALLACE HUNT

Mr. Hunt acknowledged the indebtedness of the Founder Societies to the architects of the building, and in delivering the key to E. E. Olcott, President of the Trustees of the United Engineering Society, he expressed the satisfaction of the three Societies that in the design and erection of the building no difficulties arose between the Committee and its architects or builders and expressed the wish that under the care of the Trustees the library would develop into one of worldwide influence and its resources be freely extended to all; that the home of engineering would ever be freely open to whatever will bring power, aspirations, nobler ideals, or more fruitful lives to the generations of men to come.

E. E. OLCOTT

In receiving the key Mr. Olcott, as President of the Trustees of the United Engineering Society, voiced the feeling of the members when he said that the three societies, retaining their individuality, but forming one grand enduring whole, after the manner of the federation of our States—stand united, but individual. The symbol of the new building and its aim is freedom, coöperation, and the open-door.

ANDREW CARNEGIE

Mr. Carnegie made a short address in which he expressed his pleasure in the beauty of the structure, the plans of the architects, which were in accordance with his ideas of what the building should be, and the spirit with which the societies, architects, engineers and builders had worked together toward the consummation of the ideas and plans evolved. He emphasized the value of coöperation, pointing out that whenever men coalesce to do some good work, a unification and consolidation takes place. His optimistic view of human progress was shown in his remark that quite apart from whatever evil exists, there is this principle of improvement inherent in us: today is better than yesterday, and tomorrow will be better than today. Mr. Carnegie said that one of the advantages which the American has over the man of any other country lies in his ability and disposition for coöperation, due to our political institutions which make every man the peer of any other man, every man's privilege any other man's right.

ARTHUR TWINING HADLEY

"The Professional Ideals of the Twentieth Century" was the subject of an address by Dr. Arthur Twining Hadley, President of Yale University. He said in part that the really important history of a nation is the development of its ideals and standards. The specific things that it does are important, not so much for their own sake, as for the sake of the evidence they give as to the trend of the nation's thought. In the history of engineering progress it is the thoughts of the successive builders and the influence of that thought upon the conduct and ideals of other men that we care about. That which helps us to understand the past and inspires us with hope for the future is the story of men who did things—their struggles and their discoveries, their trials and their successes.

A hundred years ago engineering was but a subordinate branch of the military art, but has become today a dominant factor in the practice of every art where power is to be applied with economy and intelligence. A building like this is therefore a symbol of all that is most distinctive in the thought of the century that has gone by. A hundred years ago a building that symbolized the achievements of the engineer was beyond man's dreams, because the world at large had neither felt the need of his work nor dreamed how soon it would be seeking his leadership.

But a large part of the professional duty of the engineer yet remains to be accomplished. This is a clear conception of the public service on which his profession is based, the public service which his profession can render, and the public duty which its members owe. Two distinct standards, the technical and the ethical, must be combined in order to secure the best professional services.

A man who believes that he is hired to carry out another man's ideas can never claim a position of actual leadership but remains a paid servant. A group of professional men who regard this as a proper view thereby forfeit a claim to stand in the first rank socially and politically, and voluntarily accept a position of the second rank.

There are three professions today which do not regard themselves as servants, but as masters—that of the financier, the journalist and the politician. If the engineer and the lawyer accept positions as servants, simply putting their technical knowledge at the disposal of merchant, journalist or politician who will pay the highest price for it, it is not simply a confession of inferiority—it is a dereliction of public duty.

We celebrate today, and we are justified in celebrating, the recognition of science as a necessary guide in the conduct of the material affairs of each man's business. Half a century hence, when our descendants shall meet in this building or some greater building, they will celebrate a yet greater thing—the recognition of the right of men of science to take the lead in enlightening the thought of the people on public affairs and the responsibility of filling the highest positions in the service of the commonwealth.

CHARLES WALLACE HUNT

After President Hadley's address, Mr. Hunt declared the building of the Engineering Societies duly dedicated to the advancement of the engineering arts and sciences in all their branches. The meeting was adjourned.

UNVEILING A BUST OF MR. CARNEGIE

At the close of the Dedication Exercises, E. E. Olcott, President of the United Engineering Society and a small party of ladies and gentlemen escorted Mr. and Mrs. Carnegie to the Library where a bronze bust of Mr. Carnegie, executed by Mrs. Cadwalader Guild, was unveiled by the withdrawal of a flag by Mrs. Carnegie. It was presented by the Past Presidents of the Founder Societies.

SECOND DAY OF DEDICATION

On Wednesday afternoon, April 17, which was set aside as Founders' Day, the Dedicatory Exercises were continued, when John W. Lieb, Jr., Vice-President of this Society and Past President of the American Institute of Electrical Engineers, presided.

The meeting was held under the auspices of the Founder Societies, the American Institute of Mining Engineers, The American Society of Mechanical Engineers and the American Institute of Electrical Engineers for the purpose of receiving the greetings and felicitations of foreign and national engineering societies and institutions of learning and members of the Founder Societies and associate societies.

Mr. Lieb spoke for the members and friends of the Founder Societies and of their progress which made it possible to assume the responsibility for the land upon which the building was erected. He spoke of the magnificent gifts which the Founder Societies have received—in some cases complete and valuable libraries, which are the nucleus of a splendid collection of engineering literature which will undoubtedly become the greatest engineering and scientific library in America.

He acknowledged the splendid work of the Conference and Building Committee which was effected through their untiring and coöperative efforts, and on behalf of the Founder Societies extended a welcome to the representatives of the Sister Societies and institutions of learning, and hearty thanks for their interest in the dedication. To the representatives of the Sister Societies from abroad he extended the hand of professional fellowship and an invitation to share the festivities. Mr. Lieb said that engineers have ever been leaders in promoting international friendships, and by their international congresses have established most enduring cordiality of relations between large bodies of influential men, separated by national boundaries but having common professional ideals and the same spirit of enlightened progress. The engineering societies are now enjoying, through the generosity of Mr. Carnegie and the coöperation of their members and friends the realization of hopes cherished for years, and the opening of this building opens a new era for the engineering profession in this country. He said that the new facilities which the Societies now have at their disposal should go far toward making coöperation among the various branches of the profession more effective—securing to the engineer that high standing in the community to which his accomplishments, both literally and constructively speaking, justly entitle him. Mr. Lieb expressed the hope that the new building would prove an inspiration for the highest professional ideals, to the increase of human knowledge and to the advancement of civilization.

ADDRESS BY THE PRESIDENT OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Mr. Lieb then introduced Dr. Samuel Sheldon, President of the American Institute of Electrical Engineers, who spoke on behalf of that Society. Dr. Sheldon paid a tribute to the simplicity, the beauty and substantiality of the new edifice. He called attention to the membership of the Founder Societies, and stated that, at the present rate of growth, in 1920 the membership of the three Founder Societies would be doubled. He spoke especially of the extraordinary growth of the electrical profession.

ADDRESS BY THE PRESIDENT OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

Prof. F. R. Hutton, President, responded for this Society. He stated that the duty of the mechanical engineer is to generate or liberate power and to design and create apparatus for the broad field of manufacture. He pointed out the value of the engineer to the several stages of production.

Professor Hutton concluded by saying, in summing up his remarks, "This building is a gift to favor production as a factor in creating wealth, itself an antecedent to progress in art, civilization, culture, and literature. It should stand in its city as a monument for sound thinking on the position of the engineer and his relation to wealth and its production by knowledge and by skill working in accordance with natural law, and therefore for the significance of engineering education as favoring such sound thought. As a consequence of these the community as a whole, as well as the organizations directly benefited by the building, owe a debt of obligation to Mr. Carnegie who has made all this possible.

ADDRESS BY THE PRESIDENT OF THE AMERICAN INSTITUTE OF MINING ENGINEERS

Dr. John Hays Hammond, President of the American Institute of Mining Engineers said that this is unquestionably the era of the engineer the world over, and especially is this true of America. To the skill of her engineers in the exploitation of her unparalleled resources America owes her recognized preëminence in the industrial world. In the development of the new fields of industry the engineer has played a conspicuous part and has contributed his labors to the sum of achievements in the advance of civilization: he said that the mining engineer is the pioneer of civilization; penetrating the jungles of the tropics and traversing the ever frozen North in the quest for gold, he has sometimes discovered a new territory for human activity. The mining engineer recognizes the indispensable coöperation of his confrères and extends fraternal congratulation for the common success in the wise provisions of the generous donor of this clearing house of engineering information.

OTHER ADDRESSES

Other addresses were made by T. Commerford Martin, President of the Engineers' Club; Sir William Henry Preece, representing The Institution of Electrical Engineers of Great Britain; Walter C. Kerr, representing Cornell University; R. A. Hadfield, President of the Iron and Steel Institute; Dr. Frederick Eichberg, of Der Verband deutscher Electrotechniker; Dr. John Findlay Wallace, for the American Society of Civil Engineers; Dr. Henry S. Pritchett, President of the Carnegie Foundation for the Advancement of Teaching; Mr. Charles Kirchhoff, Der Verein deutscher Eisenhüttenleute; Mr. Carl Hering, La Société Internationale des Électriciens de Paris; Leon Gaster, the Faraday Society of Great Britain; Mr. John W. Lieb, Jr., the Associazione Elettrotecnica Italiana and Societa degli Ingegneri ed Architetti Italiani; Dr. F. S. Archenhold, Direktor des Treptow Sternwarte; Captain W. J. Baxter, U. S. N., President of the Society of Naval Architects and Marine Engineers.

Mr. Lieb read several congratulatory letters and telegrams, among which were those from Lord Kelvin, Dr. J. H. T. Tudsbury, Secretary of the Institution of Civil Engineers of Great Britain; the Council of the Institution of Mining and Metallurgy; Directeur du Conservatoire National des Arts et Métiers, Paris; The International Bureau of Weights and Measures, Sévres, France; the Society of Marine Architects, Berlin.

CONFERRING THE JOHN FRITZ MEDAL ON DR. ALEXANDER GRAHAM BELL

The John Fritz Medal was conferred upon Dr. Alexander Graham Bell in the presence of the distinguished engineer in whose honor loyal and admiring friends founded the medal, to be awarded for notable scientific or industrial achievement. Mr. Charles F. Scott as the Chairman of the Board presented the medal to Dr. Bell in recognition of his invention and development of the telephone. He spoke of the significance of awarding the medal upon tho eccasion of the dedication of the building, since the coöperative movement by which the National Engineering Societies joined in founding the medal did much to develop the sentiment of which this building is the outcome. This is the third award of the medal, the first being in 1905 to Lord Kelvin for his work in telegraphy and other scientific achievements, and the second to George Westinghouse, in 1906, for his invention and development of the air brake.

CONFERRING MEDALS ON THE SECRETARIES OF THE FOUNDER SOCIETIES

Distinguished Service Medals were presented to the Secretaries of the three Societies—two of whom had served for twenty-three years and the third for twenty-two years. The presentation address was made by Dr. Albert R. Ledoux, in which he paid a tribute to their several abilities, their qualifications of mind and heart for the positions and to their splendid achievements which have developed the societies during their official incumbency from small beginnings to an aggregation of nearly 12,000 members.

SECRETARY POPE

In a short outline of the careers of each, Dr. Ledoux said of Ralph Wainwright Pope, the Secretary of the American Institute of Electrical Engineers, that he was born August 16, 1844, educated in Great Barrington and Amherst College. In 1859 he entered the service of the Housatonic Railroad, and during the Civil War was with the United States government service as expert telegrapher. Later he was connected with the American Telegraph Co., the New York, New Haven and Hartford Railroad, and with the famous Collins Overland Telegraph Expedition, which the success of the Atlantic Cable prevented from establishing connection with Europe across the wilds of British Columbia, Alaska and Siberia. Subsequently, Mr. Pope was for ten years in the service of the Gold and Stock Telegraph Company, resigning the position of Deputy Superintendent in 1883. From that date until 1888 he was actively engaged in editing and publishing technical electrical papers in New York. He was the organizer of the Telegraphers' Protective League and the Gold and Stock Life Insurance Association. He is a member of the New York Electrical Society, and Honorary Member of the Franklin Institute. In 1887 he began devoting his entire time to the duties of Secretary of the Institute, and has been reëlected without opposition twenty-two times, an evidence in itself of the appreciation of his services.

SECRETARY HUTTON

Dr. Ledoux said of Professor Frederick Remsen Hutton: Dr. Hutton was born in New York, May 28, 1853; he received from Columbia the degrees of A.B. in 1873, M.E. in 1876, Ph.D. in 1882, and Sc.D. in 1904. For many years he has been connected with Columbia as student instructor in Mechanical Engineering; was appointed Adjunct Professor in 1881; Professor in 1890, and was Dean of the Faculty of Applied Science for many years. At Columbia he built up the most complete mechanical laboratory possessed by any technical school. Among his many duties he found time for advancing the interests of The American Society of Mechanical Engineers, for serving as school trustee, for acting as editor of the Engineering Magazine and one of the editors of Johnson's Encyclopedia and Century Dictionary, and for writing works on mechanical engineering, power plants, heat engines, machinists tools, the gas engine, etc. Professor Hutton was elected to the office of Secretary of The American Society of Mechanical Engineers in 1883, and was reëlected for twenty-three successive years, resigning in 1906, after which he was elected to the presidency. Upon the formation of the United Engineering Society, Professor Hutton was made a trustee and a member of the Joint Conference and Building Committee which had charge of the design, erection and maintenance of the Engineering Societies Building.

SECRETARY RAYMOND

Dr. Rossiter Worthington Raymond, the Secretary of the American Institute of Mining Engineers, was born in Cincinnati, Ohio, April 27, 1840. He graduated from the Brooklyn Polytechnic Institute in 1858, and later took courses at the Universities of Heidelberg and Munich, and entered the mining academy at Freiburg, Saxony. In 1861 he enlisted in the Union Army, and in 1864 resigned with the rank of captain. Since that date Dr. Raymond has practiced as consulting and mining engineer and metallurgist. In 1867 be became the editor of the American Journal of Mining, now the Engineering and Mining Journal. In 1868 he was appointed U. S. Commissioner of Mining Statistics. A few years afterward he became lecturer in economic geology at Lafayette College, receiving the honorary degree of doctor of philosophy in 1870, and from Lehigh

University in 1906, the degree of doctor of laws. In 1871, upon the establishment of the American Institute of Mining Engineers, Dr. Raymond was chosen vice-president. He was thrice reëlected president and was made secretary in 1884, since which time he has been annually reëlected the executive of the Institute. He has written essays upon the Mining Laws of the United States and a history of mining law, published by the United States Geological Survey. He has given lectures on mining law before the students of the school of mines and the law school of Columbia University. In 1893 Dr. Raymond was admitted to the bar of the Supreme Court of New York State, and subsequently to the Federal Courts. In 1885 he was one of the three State Commissioners of Electrical Subways of the City of Brooklyn, and for many years was its secretary. He prepared the final report which is still quoted as one of the most important contributions to municipal engineering. For twenty years he was consulting engineer to the New Jersey Iron and Steel Company, the Trenton Iron Company, and others of the mining and metallurgical corporations controlled by the firm of Cooper and Hewitt. He is the author of articles on "Labor and Law," "Labor and Liberty" and the "Life of Peter Cooper."

THE MEDALS

Doctor Ledoux then presented to the three Secretaries, Mr. Pope, Professor Hutton and Doctor Raymond, the medals given by the three societies to their respective Secretaries. They were designed and executed by Victor Brenner. Upon one side is engraved the figure of a youth holding in his hand a tablet representing the spirit of invention and research; enveloping him is a cloud of steam rising from a modern locomotive, typical of mechanical engineering. Above appears the top of a blast furnace. Below and at the right hand, are the emblems of the Founder Societies, encircled by an olive wreath, while opposite is a view of the Engineering Societies Building with an inscription upon which is engraved the date of the dedication. Above the figure are suggestions of the work of the electrician and miner represented in the one by a high tension electric line, and the other by a man operating a power drill. Upon the obverse are inscribed the name of the recipient and the circumstances of the bestowal.

Professor Hutton responded in behalf of the recipients of the medal, in a short eloquent address, after which the Chairman declared the Dedication Exercises of the Engineering Societies Building closed.

No. 1140

THE ORDNANCE DEPARTMENT AS AN ENGINEERING ORGANIZATION

By WILLIAM CROZIER, BRIGADIER-GENERAL, CHIEF OF ORDNANCE, U. S. A.

I would remind you of Noah Webster's definition of engineering as the science and art of utilizing the forces and materials of nature. It is probable that not many who are familiar with the science which enters into the subject of engineering make claim to the title of engineer which is not justified, by reason of their unfamiliarity with the practice of the art. I think it can be said that there is no disposition to dispute the right of those who have investigated deeply the natural sciences, without which engineering would be merely a rule of thumb process, to take rank as engineers; but at what stage it is to be conceded that those who practice the art, commencing with the mechanics, advancing to the foremen, considering also the superintendents, and even scrutinizing somewhat the administrators, are to be granted the right to call themselves engineers is not quite clear.

2 The creations of the Ordnance Department with which you are all more or less familiar, either through inspection or through description and illustration in the daily and periodical press, attest the practice of the art of engineering construction, and men who are familiar with the methods by which results of magnitude are accomplished, know well that powerful engines, and strong and ponderous but delicate machines are not produced without the initial application of science of a high order. There is, however, little opportunity or temptation for those who are engaged in civil occupations, even for those whose profession it is to produce structures akin to the works of ordnance constructors, to critically examine and analyze the mechanisms which are manufactured for purposes of defense, and to form an estimate of the degree of scientific as well as of mechanical skill which is brouht to bear in their production. This building in

Presented at the April 1907 (New York) meeting of The American Society of Mechanical Engineers, which was the professional session held by the Society during the week of Dedication of the Engineering Societies Building, and forming part of Volume 29 of the Transactions.

which we are gathered this evening, generous product of a noble impulse, is an inspiration to anyone whose duty it is to deal with the forces and materials of nature; and in an effort to show you that the officers of the army, who produce the weapons with which we wage our happily infrequent wars, follow the processes of thought and computation and design which precede construction, involving a knowledge of basic principles and the deduction of methods therefrom, in such manner and to such degree as to justify a claim to scientific knowledge and employment, and to demonstrate their worthiness to be classed with you as engineers, I will explain tonight briefly, and by way of illustration merely, a little of the scientific process by which ordnance material is designed.

3 In thinking of the subject of weapons the first which naturally comes to mind is the gun, which, whether large or small, is the principal weapon with which armies or fortifications are armed today. Although there is plenty of science in the design of small arms, I will leave them and arrest your attention upon certain points in the design of guns of larger size. I will not go much into theory in relation to gun construction, because a little later I am going to ask you to follow me somewhat more closely through some theoretical considerations accompanying another class of construction; and the most of what I shall say in regard to the theories upon which our designs are based is not new, and is found in the text books on ordnance construction; but perhaps I may be able to point out certain applications and consequences which have not been generally realized, or set forth in publications.

4 A thick cylinder, built to withstand the highest possible interior pressure which is one of the objects to be attained in the construction of cannon, is not of frequent application in the arts; and therefore civilian mechanical engineers have not had much occasion to study its attributes, methods of construction, and limitations. It is well known to engineers, however, that when such a cylinder is subjected to an interior pressure the concentric layers of metal near the bore are subjected to much greater tension than those near the outer periphery of the cylinder; the relative tensions to which the layers are subjected, or rather the circumferential extension of these layers, since both the circumferential or tangential tension and the pressure in the direction of the radius contribute to this effect—are shown by the curve in the figure on the following page.

5 The thickness of this cylinder is equal to the diameter of the bore, which can be shown to be that beyond which it is not useful to increase it, because of the slight gain in strength which would result. As the

curve of extensions is drawn to scale, the interior ordinate repre senting the elastic limit in extension of the material of which the cylinder is formed, it is seen at once how very unequally the different concentric layers are extended; the outer one experiencing less than one-third of the strain which is brought upon the layer at the bore. The resistance of the cylinder can be represented by the product of its thickness multiplied by the mean extension, as taken from the curve; which is an expression equivalent to that for the area of the surface

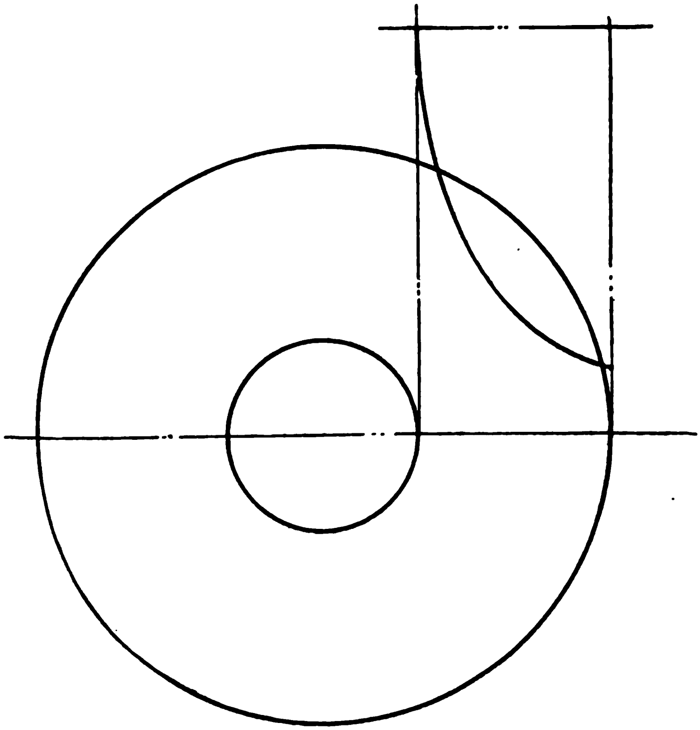

FIG. 1 TANGENTIAL STRAINS IN A SIMPLE CYLINDER SUBJECTED TO INTERIOR PRESSURE

included between the curve, the ordinates corresponding to the inner and outer radii of the cylinder and the axis from which the ordinates of the curves are set off. If we could manage so that all the concentric layers of the cylinder should be equally extended by the interior pressure, the curve would become a straight line drawn through its upper point, and the resistance of the cylinder would be measured by the rectangular area lying under this straight line. The loss of efficiency, due to the inequality of the strain, is represented by the large triangular area lying between this straight line and the curve. It is the province of the designer of ordnance so to utilize his material as to diminish this area. You all know the process used, which is to form the gun of concentric layers shrunk one upon another, so that the finished gun shall have the layers of the inner cylinders, near the bore, compressed tangentially, while those of the outer ones are correspondingly extended. The interior pressure can then attain some magnitude before the metal of the bore is brought to a neutral state,

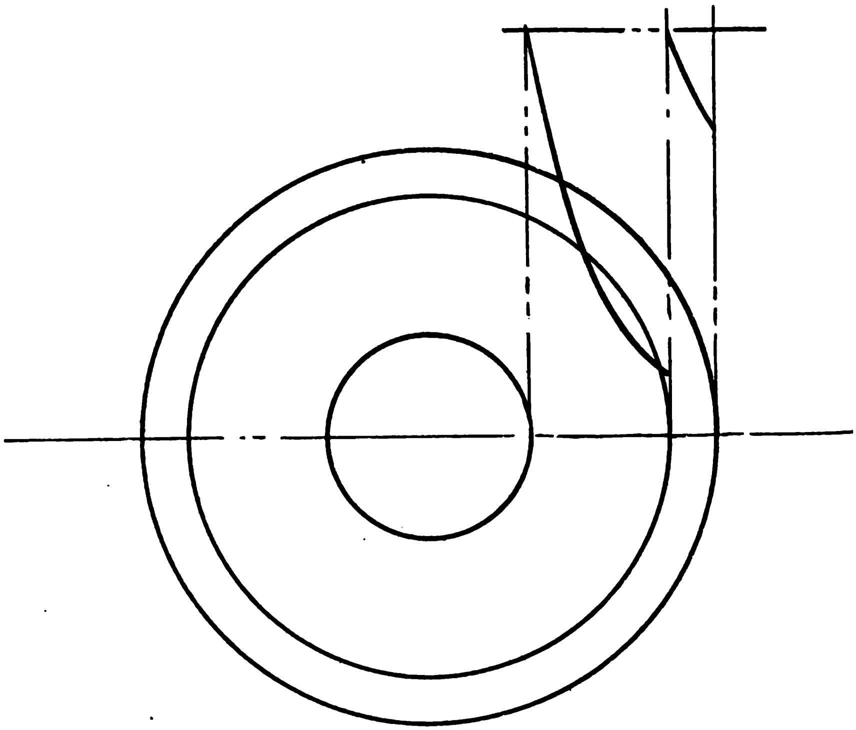

FIG. 2 TANGENTIAL STRAINS IN A COMPOUND CYLINDER ASSEMBLED BY SHRINKAGE—OUTER CYLINDER TOO THIN

and there can be added to this pressure as much as the entire pressure in the case of the simple cylinder, before the metal of the bore is brought to a state of elastic extension up to its limit; and this without overstraining any of the outer layers, if the gun is properly constructed.

6 This explanation is very plain and very easily understood. It does not pass the comprehension of the foreman, or the layman; and an appreciation of its justness and a recognition of the necessity of its application does not constitute a sufficiently high order of mental

achievement to justify the title of engineer as accompanying its mastery. The real engineering process comes in the quantitative analysis which determines the amount of the shrinkage, or the difference in diameters of the cylinders which are shrunk upon each other, in order to get the best effect from the material, and the magnitude of the pressure which the finished cylinder is capable of supporting. This analysis involves a knowledge of the materials, and an intelligent use of the science of mathematics, which is the soul of the engineer's profession, and without knowledge of the application of which it seems

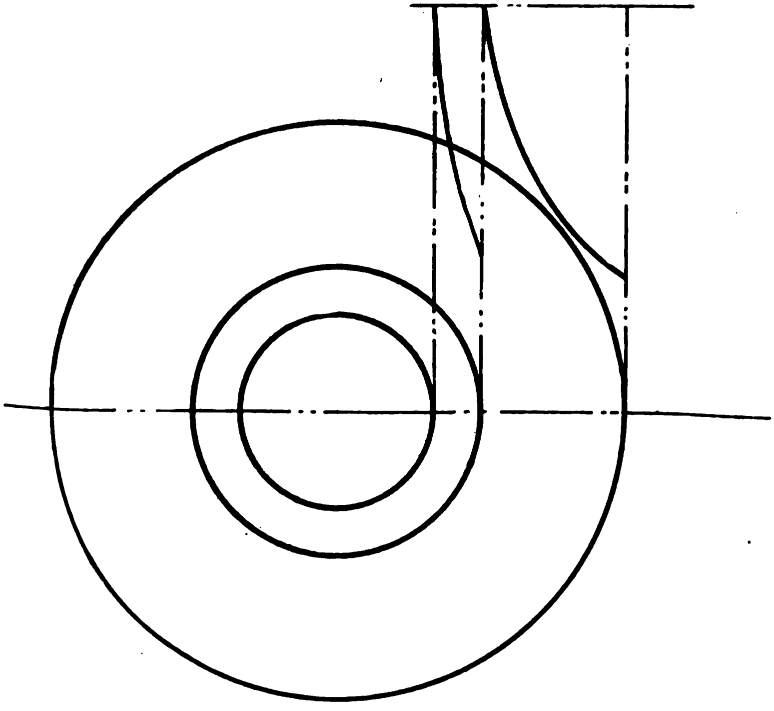

FIG. 3 TANGENTIAL STRAINS IN A COMPOUND CYLINDER ASSEMBLED BY SHRINKAGE—INNER CYLINDER TOO THIN

to me that he can not lay full claim to the title. I will content myself here with a qualitative analysis only, and will not go into the mathematics of the subject for the reason that, although I believe you would be interested therein if you had the time necessary to devote to the subject, I intend to be a little more mathematical later on with reference to another computation, as I have said.

7 The extensions in the layers of two concentric cylinders shrunk one upon another, are shown by the two curves in Fig. 2 and it is

easily seen that if, the shrinkage be properly adjusted, the metal at the interior surface of both cylinders will be brought to its elastic limit of extension at the same time by the interior pressure. Inspection is sufficient to show that the mean ordinate of these two curves is greater than that of the curve corresponding to the simple cylinder previously spoken of; and it is also quite apparent that the total area above the curves is less.

8 In addition to the adjustment of the amount of shrinkage in order to secure the best result from our compound cylinder, there is also that of the length of the radius of the circle of contact of the two

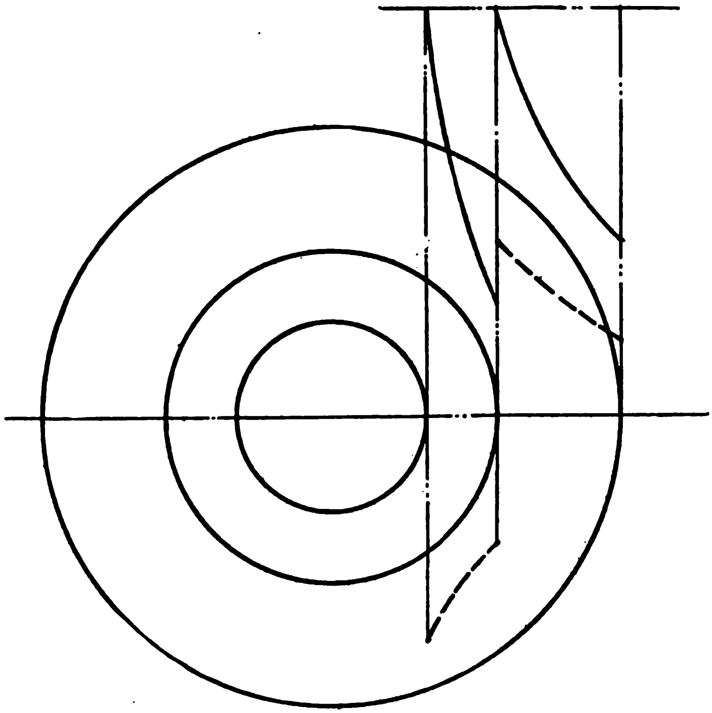

FIG. 4 TANGENTIAL STRAINS IN A PROPERLY PROPORTIONED COMPOUND CYLINDER, ASSEMBLED BY SHRINKAGE

cylinders. In the compound cylinder shown the outer tube is too thin, and there is, therefore, too small a departure from the curve of extensions of the simple cylinder. In the next compound cylinder the inner tube is too thin and, therefore, the thick outer cylinder shows a very close similarity to the disadvantageous curve of the simple cylinder. An application of the methods by which maximum and minimum states of a function are determined would show that the most advantageous result is obtained when the radius of contact is a mean proportional between the radius of the bore and that of the outer circle of the compound cylinder. In this case the curve of extensions of each cylinder is shown in Fig. 4 which corresponds to the best result which can be gotten from a compound cylinder of two layers.

9 In this figure there is also shown the state after the completion of the shrinkage, and before the interior pressure is applied. The dotted curve below the axis represents the compressions of the layers of the inner cylinder, while the other dotted curve shows the corresponding extensions of the outer one.

10 Now having gotten the best result obtainable in the compound cylinder of two layers, the question arises as to how this result may be improved upon; and the answer is by increasing the number of cylinders, so that the curves of extension of the layers of each, lying between ordinates which are closer together, will have no points as low as the inferior extremities of the two curves which are shown; thus again raising the mean tension of the curves and still further diminishing the total area lying above them.

11 And again the question arises whether there is any end to this process, other than a practical limitation as to the thickness of the cylinders which can be machined and shrunk together. The limit is arrived at by consideration of the state of the inner tube in a finished cylinder. We see by the dotted line the state of compression of this cylinder with two layers, properly proportioned. If the number of layers be increased the compression of the inner cylinder will be increased, and after a while we will arrive at the elastic limit under compression of the metal of this cylinder, beyond which we must not push it.

12 A computation would show that this result can be reached by the employment of four concentric cylinders, of material equal in quality to that of the inner tube. The compound cylinder could then be safely subjected to a pressure which would carry the metal of the bore through the range from compression to its elastic limit to extension to its elastic limit, and if these two limits were equal the range would be double either of them; and we see that by the process of building up under shrinkage we would have doubled the strength of our compound cylinder over that of the simple cylinder of the same thickness. Since we must not compress the inner cylinder beyond its elastic limit, it is evident that we can not go any further than this either by an increase in strength or by a multiplication in number of the outer cylinders, unless we are to make these cylinders of more rigid material, that is, of material having a greater modulus of elas-

ticity than that of the inner tube, which we have not thus far been able to find. There follows a result which has not been very prominently brought to attention, namely, that a gun formed by wrapping a tube with wire can not be made of any greater theoretical strength than one of as many as four concentric cylinders, notwithstanding the greater strength and the multiplicity of layers of the wire envelope.

13 A practical advantage is had in that, in such a cylinder, there is a greater reserve of strength beyond the elastic limit of the tube and, therefore, we are justified in using a smaller factor of safety and working the compound wire cylinder more nearly to the limit of its theoretical strength. There may be also an advantage of cheapness of construction, since wire of great strength can be manufactured at much less cost than the large forgings which are used in gun construction.

14 For an exposition, in its earlier stages, of the theory upon which the gun is constructed, we are indebted to Lamé, the French scientist who, in his "Lessons on Elasticity," gave an early analysis of the strains to which the elements of a hollow cylinder are subjected. His work was followed and amplified by Gadolin in Russia, by General Virgile of the French service, and by Colonel Clavarino of the Italian army; while the latest refinement in the formulae as we use them now was made by Colonel Birnie of the United States Ordnance Department. General Rodman, whose name is one of the greatest in the history of ordnance, made use of the principle of initial compression of the metal of the bore, which he accomplished by cooling from the interior the large castings from which his guns were made, which process was replaced by the more exact one of shrinkage, when forged steel cylinders of limited thickness and much higher physical qualities replaced the masses of cast iron of which the Rodman guns consisted.

15 An example of the blundering application of a good principle, as when an attempt is made without the clear guidance of theory to practice an art which should be founded upon science, is seen in the Parrott guns of our civil war time, which were formed by shrinking a band of wrought iron over the breech portion of a cast-iron body. The principle was good, and the strength of the guns should thereby have been increased; but because of the lack of application of mathematical analysis to the determination of the proper amount of shrinkage which should have been used, the operation was grossly overdone, and the guns by many failures, suffered in reputation and discredited a good idea.

16 I will now leave the subject of guns and pass to one which is even less frequently brought to the attention of those who do not have to concern themselves with ordnance construction. I refer to the

carriages upon which the guns are mounted and maneuvered; and with reference to these I will ask you to consider by way of a typical illustration, the method by which the recoil of the gun is controlled; since this process is one which is even more unfamiliar in the commercial practice of mechanical engineering than is the use of the thick cylinder. A 12-inch gun in its recoil has an energy of practically 1000 foot tons, and to absorb this in the short distance of three feet without shock and without undue strain upon any part of the structure, which must endure many repetitions of it, is a necessity which I do not understand as arising in any other class of construction.

17 Fig. 5 shows the general method by which this is accomplished. A piston is attached to the recoiling gun and is drawn through a cylinder filled with liquid, generally oil; the resistance which checks the recoil is produced by forcing the oil from one side of the piston to the other through small orifices. As the velocity of recoil of the gun

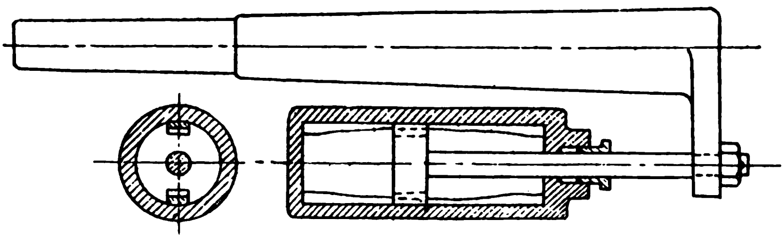

FIG. 5 DIAGRAMMATIC SKETCH OF BRAKE CYLINDER FOR CHECKING RECOIL

in its earlier stages is higher than when it is nearly brought to rest, orifices of constant size would produce a much greater resistance in the earlier portions of the recoil than in the later, and would result in a much higher strain than the mean on the piston rod, and on the cylinder and its attachments, all of which would have to be made strong enough to withstand the highest strain. It can be shown that in such a cylinder, which was the kind at first used for the purpose of checking recoil, the maximum strain is more than four times the mean. In order to reduce the strain to the mean it is necessary to vary the area of the orifices as the recoil proceeds, and one of the methods of accomplishing this is to form the orifices by cutting in the piston slots which slide over bars bolted along elements of the cylinder; the orifices are the portions ot the slots which are not filled by the bars, and as the latter are of constant width and varying depth, the size of the orifices can be varied in accordance with any desired law.

18 The computation of the curved surfaces of the bars, whose character is desired to be such that the orifices shall be diminished at a rate proper to produce constancy of pressure in the cylinder, is that to which I now invite your attention; and in describing it with sufficient clearness to be understood I will make use of certain mathematical expressions for which I would feel compelled to apologize to an audience of any other class. But the expressions will be simple, and will be easily recognized even by those whose early success has led them away from the direct application of this handmaid of the engineer into directive positions, in which their differentiations and integrations are done for them by others. I hope I shall be able to indicate a much more extensive application of mathematics and theoretical mechanics than that which I am about to show directly.

19 The problem would be much easier if the gun should start in recoil with its maximum velocity at the beginning of its motion; the subject of its control could then be handled by very little variation from the methods of analytical mechanics, as ordinarily applied. But this is not the case; as soon as the gases produced by the burning of the powder charge attain sufficient pressure to overcome the mere passive resistance, such as friction and the resistance to distortion of the band of the projectile, the gun commences to recoil, and the velocity increases until the diminishing pressure falls below these passive resistances. If the gun were free to recoil, without any kind of restraint, it would commence to do so as soon as the projectile began to move, and its velocity would increase as long as the powder gases exerted any pressure upon it, after which it would continue indefinitely at the same rate of motion.

20 There has thus far been deduced no mathematical expression for the variation of the velocity of recoil of the gun during this early period of its motion, to meet which the orifices for the flow of the oil from one side of the piston to the other in the recoil brake cylinder must increase in size; therefore we attack the subject semi-graphically as follows:

21 We assume the distance in which we wish to check the recoil, and this leaves us with two elements to compute, first, the magnitude of the constant resistance which the brake must offer in order to check the gun in the assumed distance; and second, the size of the orifices for the flow of the oil at each point of the passage of the piston through the cylinder, necessary to produce this resistance. The computations relating to the gun, the powder charge, and the projectile give us an expression for the velocity of the latter at each point of its travel through the bore, and this velocity is plotted as the ordinate of the

curve shown in Fig. 6, of which the abscissa is the distance from the starting point of the projectile, measured along the bore. This curve we will take for our starting line.

22 The mathematical expression for the ordinate of this curve is $\frac{dx}{dt}$; if we plot another curve, as shown in the same figure, whose ordinates shall be the reciprocals of those of the velocity curve, the mathematical expression for these ordinates will be $\frac{dt}{dx}$; the expression for the differential of the area under the second curve is $\frac{dt}{dx}\,dx$; that is, the ordinate into the differential of the abscissa; and the area under the curve is the integral of this expression, that is, the integral of $\frac{dt}{dx}\,dx$, which is the integral of dt, or t. That is, the area under the second curve measured out to any ordinate is the time which it takes the projectile to reach the corresponding point of the bore.

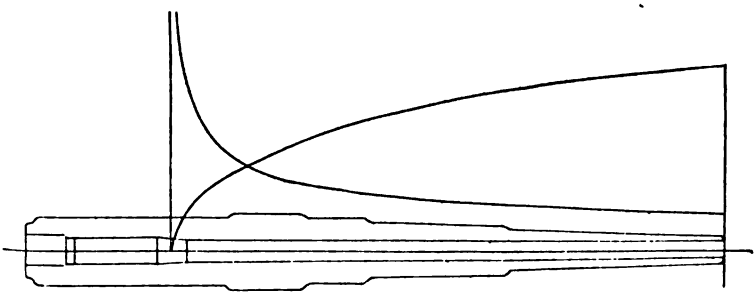

FIG. 6 CURVES OF VELOCITY OF A PROJECTILE, AND OF THE RECIPROCALS OF THE VELOCITY, AS A FUNCTION OF THE DISTANCE TRAVELED

23 By using these two curves, and plotting a third one whose abscissae shall be the ordinates of a time curve, and whose ordinates shall be the corresponding ones of the velocity curve, we obtain the curve shown in Fig. 7, which is that of the velocity of the projectile as a function of its time of travel. This curve has a point of inflection corresponding to the maximum powder pressure, when the acceleration of the shot is naturally the greatest.

24 Since the projectile is moved in one direction and the gun is moved in the opposite by the pressure of the powder gases, the velocities of motion of the two would be inversely proportional to their weights, were it not for the fact that the powder charge itself has considerable weight which must also be moved by its own pressure; therefore, we have it that the weight of the gun multiplied by the

velocity of the recoil is equal to the weight of the shot multiplied by its velocity, plus the weight of the powder multiplied by the velocity which it has, or the formula:

$$W_g V_g = w_s v_s + w_p v_p$$

25 The best theory which we can form as to the distribution of the powder gases behind the shot, while the latter is moving along the bore, is that they remain at all times evenly distributed between the projectile and the bottom of the bore. Under this supposition the center of gravity of the powder charge is always half way between the base of the shot and the bottom of the bore, which would involve a velocity for this center of gravity just one-half that of the shot; we can, therefore, substitute for the velocity of the powder charge in the

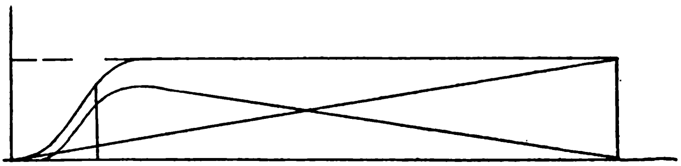

FIG. 7 CURVES OF VELOCITY OF FREE RECOIL, OF CONSTANT RETARDATION, AND VELOCITY OF RETARDED RECOIL OF GUN, AS A FUNCTION OF THE TIME

formula one-half of the velocity of the shot, which makes the formula the following:

$$W_g V_g = w_s v_s + w_p \frac{v_s}{2}$$

Solving this formula we have:

$$V_g = \frac{(w_s + \frac{1}{2} w_p)}{W_g} v_s$$

26 Since the coefficient of the velocity of the shot is a constant quantity, the velocity of recoil of the gun is directly proportional to it, and we can consider the same curve as representing the velocity of recoil of the gun as a function of the time, by bearing in mind that the scale is different. This gives us the velocity of recoil during the period in which the shot is in the bore of the gun; but the formula does not hold good after the shot leaves the bore, for the reason that, freed from restraint of the projectile, the powder gases then rush from the bore with greatly increased velocity, much greater than one-half that of the projectile, and greater also than that of the projectile itself.

27 The gases, however, still exert an appreciable pressure upon gun,the and continue for a time to accelerate its motion. We have

means of measuring the maximum velocity of the gun, upon recoiling freely, and also of measuring the maximum velocity of the projectile; By substituting these measured velocities in the first formula given, we have one in which the only unknown quantity is the maximum velocity of expulsion of the powder charge, which can therefore be deduced. For guns of similar class this figure should be approximately the same, and having tried the experiment for one gun of a class we can use the same figure in computations relating to other guns. The result of such experiments indicates that the mean of the maximum velocity with which each portion of the charge of smokeless powder is expelled from the gun is about 4700 feet per second; and substituting this figure, together with the maximum velocity of the projectile, in the first formula we get the maximum velocity of recoil of the gun, supposing always that it should recoil without retardation. By drawing parallel to the axis of time a straight line at a distance from it corresponding to the maximum velocity thus obtained, we know that the curve of the velocity of recoil as a function of time must rise to this line, become tangent to it, and continue along the line indefinitely; we are thus able to complete the curve with a very fair approximation to accuracy. The point of tangency is hard to determine; but we can remember that the exact instant at which the last breath of the powder pressure ceases to accelerate the recoil in the slightest degree is not very important.

28 Suppose now we have a constant force to retard the recoil of the gun. Such a force would diminish the velocity of recoil proportionally to its time of action, and the loss of velocity would be represented by the ordinate of a straight line such as we have drawn in the figure. By prolonging this line until it reaches the curve of the velocity of recoil, and dropping the corresponding ordinate to the axis of time, we obtain the time which would be required by such a retarding force to completely stop the gun. Subtracting from each ordinate of the curve of velocity of free recoil the corresponding ordinate of the straight line, we can plot a new curve which shall represent the velocity of recoil of the gun under the action of the brake.

29 Remembering that the curve gives this velocity as a function of the time, the expression for it is $\frac{dx}{dt}$; the differential of the area under the curve is $\frac{dx}{dt}dt$; and the area itself is the integral of this expression; thus we have $\int\frac{dx}{dt}\,dt = \int dx = x$. Therefore, the total area

under this last curve is the total length of recoil. From the manner in which the ordinates of the last curve are obtained, each one of them is equal to that portion of the corresponding ordinate of the free recoil curve which lies above the straight line; and this being true of every ordinate it follows that the total area between the inclined straight line and the free recoil curve is equal to the area under the last curve. That is to say, if we draw this straight line so as to include between it and the curve of velocity of free recoil an area equal to the assumed distance in which we wish to stop the recoil of the gun, this line will give us the total time which would be required to check the recoil, and the maximum velocity of the recoil divided by this total time would give the negative acceleration of the recoil, or the retardation of the gun. The mass of the gun multiplied by this negative acceleration is therefore equal to the retarding force; which is the first of the elements that we were seeking. The method of drawing the straight line so as to cut off between it and the curve the area equaling the assumed length of the recoil involves measuring, with

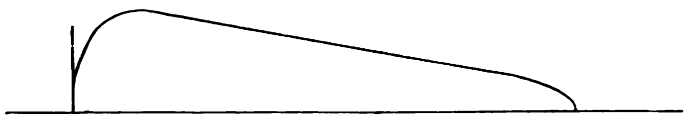

FIG. 8 CURVE OF VELOCITY OF UNIFORMLY RETARDED RECOIL, AS A FUNCTION OF THE DISTANCE RECOILED

a planimeter or otherwise, the area under the portion of this curve which is really a curve; with this area measured the process is a simple one.

30 Having the total resistance which the brake must offer in order to check the gun in our assumed distance, we must also have, in order to properly proportion the orifices, the velocity of recoil of the gun, which is that of the motion of the piston through the cylinder, at each point of the recoil, as well as at each instant thereof; that is, we must have the velocity of recoil as a function of the distance recoiled. From the last curve drawn we are able, as just explained, to obtain this; for, by measuring the area under this last curve out to any ordinate we obtain the distance recoiled in the time corresponding to the ordinate. By plotting this distance as the abscissa and the corresponding velocity as the ordinate, we obtain a new curve of the velocity of recoil as a function of the distance, which is shown in Fig. 8.

31 The next step involves a formula with which you are all familiar; $v^2 = 2gh$, in which v is the velocity of flow of the liquid through

the orifice in the lower part of a containing reservoir, and h is the height of the upper surface of the liquid above the orifice. If Δ is the weight of a cubic unit of the liquid, the pressure per square unit at the height of the orifice is equal to $h\Delta$, which gives us $h\Delta = p$. p is equal to the total pressure, or resistance, of the brake divided by the area of the brake piston; representing this area by A, and substituting the value of h in the formula for v, solving it we get

$$v = \sqrt{\frac{2\ g\ \bar{B}}{\Delta A}}$$

As all the terms here are known we get the value of v; that is, the velocity at which the liquid must be forced through the orifices in the piston, in order to produce the constant resistance which has been determined.

32 Since all the liquid which is displaced by the piston in its motion through the cylinder must pass through the orifices to the other side, the velocity of the piston multiplied by its area must equal the velocity of the flow of the liquid through the orifice, multiplied by the area of the orifice, which is expressed by the equation

$$A\ v_g = a\ v_o$$

v_g being the velocity of the gun or piston, and v_o being that of the oil, from which we get

$$a = \frac{A}{v_o}\ v_g$$

That is, the area of the orifice is equal to the constant factor $\frac{A}{v_o}$, multiplied by the velocity of recoil of the gun. Since the area of opening is thus proportional to the velocity of recoil, the same curve which we have already drawn will answer, by proper adjustment of the scale, as the curve of the area of opening of the orifice as a function of the distance from the initial point of the piston.

33 In this computation, I have paid no attention to the contraction of the liquid vein. The pressures which are used in the hydraulic cylinders of gun carriages are higher than those which are apt to be encountered in reservoirs from which the flow has been experimentally measured; with the ordinary high power gun and the recoil cylinders of the size generally employed, the pressure runs from 1000 to1 500 pounds per square inch, while with mortars, which are lighter in comparison with the weight of the projectiles and therefore have a higher velocity of recoil, the pressure runs up as high as 4000 or 5000 pounds

per square inch. With such pressures the vein is considerably contracted, and we have used a coefficient as high as 1.67.

34 In the last experiments, with the mortar carriage in which we used this coefficient we had difficulty in obtaining a proper indicator diagram, when we attempted as usual to check the theoretical work by the use of that instrument. The work was carefully gone over, and computations were made independently by several persons, but we were unable to make the discrepancy disappear. Finally we dismounted the hydraulic cylinders and measured them with a star gage, when we found that they had been over-bored some 0.03 of an inch from the carefully prescribed diameter. The pistons were bushed so as to take up this unauthorized and unexpected clearance, and the trouble disappeared; the indicator diagram assumed a proper form; the science and the art of gun carriage construction were again on speaking terms with each other, and harmony reigned in the Ordnance Department.

35 In explaining some little of the methods which are followed in the work with which that department is charged, I have hoped that you would recognize some kinship between the workers in our class of problems and those who struggle with the problems of civil engineers, but when I tell you that the anxious designer finds himself puzzled and dismayed by what afterward turns out to have been a workshop error on the part of those charged with working the design into material, and that holes are bored 0.03 of an inch larger than they ought to be, I expect you to say to yourselves: "These men are our brothers, their joys and woes are our very own."

36 The case of a recoil brake computation which I have hastily run over is the very simplest one; it meets with many variations in practice. The most simple variation is when the gun recoils up an inclined slide, down which it runs after recoil again to the firing position. In this case the hydraulic brake is assisted by gravity, which has to be taken into account in checking the recoil. Another common variation is when the gun carriage is so adjusted that the recoil of the piece is directly in the line of the axis, whether it be fired horizontally or at an elevation. With such carriages the piece is returned to the firing position by springs, which are compressed during recoil. If the gun be fired at an elevation the recoil is in this case assisted by a component of the force of gravity, and it is checked by the combined action of the hydraulic brake and the counter recoil springs. All of which produces a modification of the computation of the orifices for the flow of the liquid. An extreme case of variation exists in the disappearing carriage, upon which most of the guns of our seacoast fortifi-

cation are now mounted. An outline sketch of this carriage is shown in Fig. 9.

37 Many of you have seen carriages of this type, and others have perhaps seen illustrations and descriptions of them in various publications. I will however run briefly over the action which takes place when the gun is fired. The gun is mounted by its trunnions upon the upper extremities of two long levers; these levers are pivoted at their middle point in trunnion beds formed in a cradle, or top carriage, which is mounted upon rollers. To a bar joining the lower extremities of the two levers is attached a counterweight, sufficient to overbalance the gun, and these lower extremities are connected with a sort of cross-head which runs on vertical guides.

38 When the recoil takes place the middle point moves to the rear in a line parallel to the surface upon which the rollers run, while

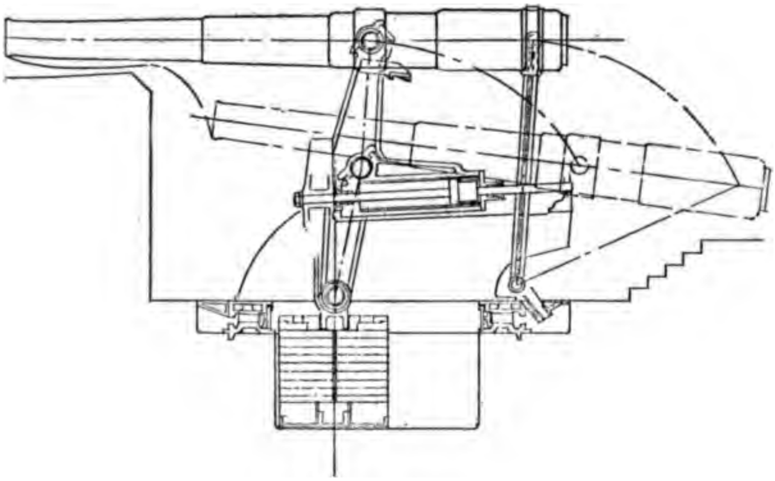

FIG. 9 DISAPPEARING GUN MOUNTED UPON BUFFINGTON-CROZIER CARRIAGE

the lower extremities of the levers move vertically upward in a straight line. It follows that the upper extremities, upon which the gun is mounted, move to the rear and downward in the arc of an ellipse. The breech of the gun is raised and lowered, for changing the elevation to correspond to the range, by two elevating arms which also serve to guide the breech during recoil, their point of attachment to the gun describing the arc of a circle. The recoil is checked partly by raising the counter-weight, but mainly by the hydraulic brake formed in this case by cylinders which are drawn over fixed pistons. It will be observed that this carriage offers a very considerable departure from the simple case in which the gun recoils horizontally in a line parallel with the axis of the brake cylinder; the gun is set in motion in a line approximately parallel to the motion of the cylinder, but it changes its direction with reference to that motion at every instant, and it moves finally nearly at right angles to it; the lever upon which the gun is mounted have both a motion of translation and a motion of rotation; the elevating arms have a motion of rotation about their lower extremities; the counter-weight moves upward in a direction practically at right angles to that of the brake cylinder. All of these masses, set in motion with different and constantly varying velocities of translation and rotation, must be brought to rest by the action of the hydraulic brake, in which the orifices should be so computed as to make its action constant.

39 There is thus offered a problem sufficiently complex to afford an abundance of interesting occupation; its solution involves the handling of equations involving some fifty terms, and the computation of the curve of variation of the orifices for the flow of the liquid is an operation requiring some ten days of close work.

40 We owe the method of computation which I have explained to General Sébert and Captain Hugoniot of the French Artillery; to which we are greatly indebted for scientific methods of ordnance construction. Indeed the French seem to have a peculiar genius for drilling into the future and extracting therefrom the hitherto unknown, and it is appropriate to mention here that we owe to them the rapid firing field gun with which the armies of the civilized world are today either already armed, or are rapidly re-arming. The essential feature of this gun is its long recoil upon the carriage, something like four feet; by reason of which the action of the gun upon the carriage is so softened that the latter does not move from its place upon firing, and the gunner can sit upon the trail, with his eye at the sight, and continue the firing as rapidly as the piece can be loaded. This improvement raises the rate of fire from about two rounds per minute to about twenty.

41 Mechanical science and art have of course greatly advanced in the last half century. The structures have increased enormously in power and performance, and have also increased greatly in complexity and refinement, necessitating more extensive, more accurate, and more highly cultivated knowledge upon the part of designers, and an enormous increase in the number of draftsmen required to translate the thoughts of the engineer into pictorial language, which can be understood by the mechanics who are to execute those thoughts, and a corresponding increase in the power and accuracy of the machines which have to fashion the material into shape, and the skill of the

persons who must operate them. Progress, in all subjects, has been defined to be the advance from the simple to the complex; and ordnance construction has shared in the progress, as thus defined, of other branches of engineering.

42 The most powerful gun of our Civil War period was the 15-inch Rodman smooth bore, firing a projectile of 480 pounds weight with a velocity of about 1500 feet per second. The drawings of this gun occupied but a single sheet, and the specifications for its manufacture could be written upon a single page. The drawings for the carriage upon which it was mounted cover two sheets of ordinary size, and the specifications cover less than half a dozen pages of ordinary handwriting. The drawings of the 12-inch built-up gun of today require about seven sheets for their representation, and the specifications are found in a printed pamphlet of some twenty pages. The sheets of drawings of the gun carriage number about twenty-five, closely covered with details, and the specifications, divided into two classes, general and special, occupy two printed pamphlets of 15 and 35 pages, respectively. The gun throws a projectile of 1000 pounds weight with a velocity of 2500 feet per second and an energy six times that of the projectile of the 15-inch smooth bore; while the rate of fire is increased from about one round in ten minutes to three rounds in two minutes. That is to say, about one hundred times as much energy can be delivered in a given time. The increase of extent and complication of the personal machine by which this result is accomplished can be appreciated by the members of similar organizations.

43 I will say a word or two about our special organization. The statutory strength of the Ordnance Department in officers is 85. Its officers are not graduated into it directly from the Military Academy at West Point, but all must serve at least a year before being eligible for service in it. Service in the department is by detail for four years at a time, after which captains and lieutenants must serve at least one year in the branch of the service from which they were detailed, before being eligible for another tour. Majors and higher officers serve also four years at a time, but there is no compulsory interval between successive details; so that their service may be continuous, although it is not necessarily so. Detail to the department, for the first tour of duty therein, follows an examination, which is either qualifying or competitive depending upon whether the number of candidates is less or greater than the number of vacancies; in the past there has usually been competition, which has often times been as great as corresponds to seven or eight times as many candidates as vacancies. Detail for subsequent tours of duty is made by a board of

ordnance officers, all senior to the grade eligible for the detail. The incentive to preparation for the examination, and for such continued effort as to merit re-detail to the department, is found in the advancement of grade which may accompany the detail; officers of all grades in the army being eligible for detail to the next higher grade in the ordnance department, of which the lowest rank is first lieutenant. If an officer once admitted is found not to be well fitted for the service, he need not be detailed for a second tour. There is thus a process of selection and elimination, with incentive, which constitutes a merit system. All officers, whether graduates of West Point or commissioned from civil life, are eligible.

44 The art of manufacture of ordnance is carried on at six large establishments, employing over 5000 workmen, of which 790 are machinists; the establishments are guarded and generally cared for by some seven hundred enlisted men. There are on the rolls of the department 90 draftsmen. At the Watertown Arsenal, near Boston are manufactured seacoast gun carriages; at the Springfield Armory, also in Massachusetts, the principal output is the musket, of which the plant has a manufacturing capacity of 400 per day of eight hours; at the Watervliet arsenal, opposite Troy in New York, there are manufactured cannon, both large and small; at the Frankford arsenal in Philadelphia, the principal manufacture is ammunition for small arms, but there is also made a considerable quantity of ammunition for small sized artillery and instruments for the fire-control and direction of artillery; at the Rock Island arsenal in Illinois, the largest of them all, there are manufactured field artillery gun carriages and other vehicles, the personal and horse equipments for infantry and cavalry, artillery harness, and small arms. For the last, the plant has a capacity of about 250 guns per day of eight hours. All of the artillery material is tested and admitted to the service at the Sandy Hook Proving Ground, in New Jersey, which also forms a practical school to which officers are sent when first detailed for duty in the department. A powder factory, for the manufacture of smokeless powder, with a capacity for about 1000 pounds per day, is in process of erection upon a reservation near Dover, New Jersey.

45 I hope the organization is one which can commend itself to the thoughtful citizen, when described to him, as one in which strenuous and wholesome effort and keen competition must necessarily be found, and to which he is willing to confide the large expenditure and vital interest involved in the preparation of the fighting material for defence.

46 I wish to anticipate a suggestion which may possibly be made, tending to separate the class of military engineers from those who

work in civil pursuits. Your lives are spent in an effort to improve the facilities of the world for increasing the happiness and promoting the general well-being of its inhabitants. You build great connecting links to enable people on one side of enormous obstacles to pass conveniently and safely to the other side; you provide means of wonderful efficiency whereby hundreds of thousands of people who are not where they want to be in this restless world, are transported daily with the speed of the wind to the places where they think they would rather be. You are even now emancipating these insatiable travelers from the necessity for combination, and are placing at the individual door a machine of infinite patience to wait during meal hours and sleeping time, and with no claim for consideration as to fatigue or ennui, until such time as the whim or convenience of its master may call upon it to carry him at railroad speed to any place to which other engineers may have built a practicable road.

47 In all this are you set apart from the military engineer who works to create means of destruction, and whose effort is not to promote the pleasure of life but to produce means for smashing and damaging, for maiming and destroying; whose utilization retards progress in the pursuit of happiness, and necessitates a process of recuperation before its interrupted course can be pursued again from the point at which it was cut off.

48 It would be almost disloyal to the enlightened giver of this splendid shelter in which we find ourselves this evening to say a word of discouragement to the efforts for universal peace in which he has shown such a profound and serviceable interest; but those efforts are not best promoted by ignoring their limitations, and by maintaining in the face of much sincere conviction that wars may soon come entirely to an end. I believe in the utility of peace conferences. I appreciate the evidence that the one of 1899 at The Hague produced an arbitration convention which has already served good purposes; and I am satisfied that it is entirely possible, and more than probable that the next conference, already arranged at that place, may improve the International Court of Arbitration so that the submission of differences to it may be more easy and inviting, and the failure to do so may be a more direct and responsible challenge to the public opinion of the world than at present. But we have only to consult history, and not very ancient history at that, to find instances of conflict in which arbitration would have been in no wise possible. The very latest of the great wars affords an example.

49 When the peace conference of 1899 first assembled at The Hague, there was an effort made to induce the powers represented to

make a binding agreement that they would submit certain classes of dispute to arbitration. When this effort failed there were substituted for its expression in the treaty of arbitration various forms of moral pressure, designed to promote a resort to this method of settling differences. The most pronounced of these forms of pressure was that embodied in Article 27 of the treaty, which declared that whenever two nations should be involved in a dispute which threatened to become acute, it should be the duty of all the other signatory powers of the treaty to remind these two that the Court of Arbitration was open to them. The article was made prominent by considerable discussion before its acceptance; but no single power considered it worth while to fulfill the duty which it had engaged to perform, by reminding either Russia or Japan that the civilized world looked to them to carry their causes of disagreement before The Hague tribunal and abide by the result. It was in this case recognized that arbitration was not possible. But I think that we can find in comparatively recent history lessons which go farther than this one, and show that in certain cases arbitration is not only impossible but would be undesirable.

50 Our war with Spain was based upon the conceived necessity for terminating the rule of her government in Cuba; we believed that her incapacity for keeping order, for providing for the security of life and property, and for preserving livable conditions in general had been so demonstrated that it was necessary to use the land and naval forces of the United States to terminate her jurisdiction therein, and deny her further sovereignty over the island. What must have been the action of a court of arbitration upon this proposition? Courts must be guided by the law and the precedent and the established order as they exist at time of trial of the case. Our contention was to terminate the possession in which Spain was firmly established by all the rules of international law. No court, whatever its sympathies or views of the general welfare might have been, could have found justification, in any of the principles to which it would have had to look for guidance, for decreeing that Spain's lawful ownership of Cuba must come to an end against her will, and that the disposition of the island, either for annexation, autonomy or independence should be turned over to the United States. There is no process which a court could have considered by which the final result might have been brought about, against Spain's protest, except that of war. If the result was desirable, here is a case in which war served a better purpose than could have been served even by a court sympathizing with the object, but guided by its conscience and by its oath.

51 Nearly half a century ago the people of a part of these United

States made up their minds finally that slavery was wrong, and should not be extended; the people of another section were equally positive and sincere and conscientious in their conviction that slavery was right and ought to be extended. The Supreme Court of the United States, following the Constitution and the statutes, found itself compelled to decide that slaves were property, and as such could be taken by their owners into the new territory of the United States, to be there entitled to its protection.

52 In the solution of this difference there was involved the question of the right of a state to withdraw from the Union. A distinguished son of Massachusetts, a veteran soldier on the Union side of the Civil War, has recently made a careful argument to show that the question of secession was not decided, was not intended to be decided and was recognized as being impossible of decision, at the time of the formation of this government. If this learned gentleman is right, and if the Supreme Court of the United States was right, the settlement of one phase of the great Civil War question by judicial process must have been entirely uncertain, and the settlement of the other, and morally speaking by far the more important phase, would undoubtedly by such process have been adverse to the conclusion which was finally reached, and of the righteousness and general benefit of which there is now no shadow of doubt in any portion of the entire civilized world.

53 In 1877 Russia went to war with Turkey in order to compel that nation to bring to an end the barbarities which were being inflicted upon the Christian people of the Balkan Provinces. In accordance with international law, Turkey was sovereign in those provinces and had the right to treat her subjects therein in accordance with the dictates of her own conscience. The war smashed this right, and brought to an end the Bulgarian atrocities, effecting the practical independence of Bulgaria. The results of the war alone would have been better than those finally secured, when a deliberative conference at Berlin partially undid the work of the sword, and left Macedonia in a subject position, to be the source of future trouble.

54 The American colonies went to war with the mother country in resistance to the principle of taxation without representation. During the progress of the war it became evident that harmony and satisfaction would not be restored by concession on the part of Great Britain of the main point contended for by the colonists. These concluded that nothing short of complete independence would satisfy their lofty aspirations and grant them that right of self-government in the struggle which they were ready to embark their lives, their

fortunes, and their sacred honor. Great Britain was very far from being ready to consider even practical, and far less complete and theoretical independence for the colonies. She had not yet learned the lesson as to the treatment of colonies which our Revolutionary War went so far in teaching her; though she never again treated other colonial dependencies as she had attempted to treat those in America, the lesson of the war was needed to show her that it was neither right nor possible nor profitable to treat colonies as regions to be drained of their wealth for the benefit of the home country. The principle of taxation without representation was well established by the usage of the world; it could not be upset by any process not revolutionary in its nature, while the withdrawal of the colonies from British sovereignty was completely beyond and without the pale of all law which could be laid down and followed by any tribunal which could have been called upon to pass upon the situation. No court would have had any choice but to deny a petition for a decree of independence, if the colonists could have been wild enough to present such a petition, or could it have been possible to convene a court for receiving it. So the fathers declared that "When, in the course of human events it becomes necessary for one people to dissolve the political bands which have connected them with another, and to assume among the powers of the earth the separate and equal station to which the laws of nature and of nature's God entitle them, a decent respect for the opinions of mankind requires that they should declare the causes which impel them to the separation."

55 Here is the whole matter. A necessity is conceived for changing the organic law, by force if resisted, and the only obligation resting upon those who decide to take the change into their hands is that they shall have such deference to public opinion as to set forth their case to the world and appeal to the right thinking for approval of their effort. If the independence of the United States was a good principle to be secured, here again is a case where war achieved a better result than could have been accomplished by arbitration.

56 It seems possible that one better skilled in the study of international law might evolve an acceptable generalization from these and other instances which could be found in history, and lay down a principle that the established order, as contained in the whole body of international law and usage, and custom, being the product of human wisdom, is subject to being wrong, and to being found inapplicable to changed conditions and relations which arise in the progress of the world; that when such is found to be the case it is clear that the existing law should be changed; but that when such change

is resisted by a community whose interest is supposedly or actually bound up in the wrong order, there is no judicial process by which the change can be effected; that the process must be a revolutionary one, and that resistance entails that the revolution must be brought about by force, that is by war. And the people which has become satisfied that the change is necessary must state its case to the world, gird on the sword, and guided by its conscience and hoping for the approval of the public opinion of mankind, must resort to the only process by which that change which it believes makes for the highest good, can be accomplished.

57 In the cases cited in which the United States has been involved, it seems to me that thoughtful people must admit either that our country has been wrong, or that the outcome has been better than that which could have been granted by any court which it would have been possible to convene at the times when we entrusted our case to the God of Battles, in belief in the justice of whose decisions we hold up our heads today.

58 May I hope that you will concede that in passing our lives in the effort to improve the means for sustaining the nation's case in an appeal, in accordance with its conscience, for some great good which it is beyond the power of any court to grant, to an arbitrament of higher jurisdiction than that of any court, military engineers are not unworthy to be classed as workers with yourselves for the supreme good of the human race.

No. 1141

PROCEEDINGS OF THE INDIANAPOLIS MEETING

The Spring Meeting of 1907 was held in Indianapolis, Indiana, May 28-31. It was highly successful by reason of the large attendance, the interest in the professional sessions, and the entertainment provided by the Local Committee.

A session was devoted to the automobile, two sessions to superheated steam, and at the other two professional sessions miscellaneous subjects were discussed.

COMMITTEES OF THE INDIANAPOLIS MEETING

The following is a list of the Chairmen of the Committees for the Spring Meeting at Indianapolis. General Chairman of the Local Committee, Mr. J. R. Whittemore; the Finance Committee, Mr. L. M. Wainwright; the Ladies' Committee, Mr. William Rockwood; the Entertainment Committee, Mr. H. H. Rice; the Hotel Committee, Mr. W. G. Wall; the Printing and Press Committee, Mr. Theo. Weinshank.

TUESDAY EVENING SESSION

The meeting was opened Tuesday evening, May 28, by an address of welcome by Mayor Bookwalter of Indianapolis, to which President Hutton responded. An informal reception was afterward held in the parlors of the Claypool Hotel.

THE WEDNESDAY MORNING SESSION

At the Wednesday morning session the reports of the Committees were presented, the business of the Society transacted, and the following reports and professional papers read:

REPORT OF THE COMMITTEE ON STANDARD PROPORTIONS FOR MACHINE SCREWS. The Committee

Discussed by,

E. H. Berry, L. D. Burlingame, G. A. Gulowsen, Fred J. Miller, Sanford A. Moss, E. H. Neff, Oberlin Smith, John W. Upp, D. A. Wallace, H. K. Jones, in behalf of the Committee; J. M. Carpenter, E. O. Goss, Prof. F. R. Hutton.

PRELIMINARY REPORT OF THE COMMITTEE ON REFRIGERATING MACHINES[1] The Committee

Discussed by,

Prof. R. C. Carpenter, F. H. Boyer, R. L. Shipman.

COLLAPSING PRESSURES OF LAP WELDED STEEL TUBES, Prof. R. T. Stewart

THE BALANCING OF PUMPING ENGINES, A. F. Nagle

Discussed by,

I. H. Reynolds, E. H. Foster.

THE ECONOMY OF THE LONG KILN, E. C. Soper

Discussed by,

Prof. W. D. Ennis, E. A. W. Jefferies, Prof. R. C. Carpenter, Byron E. Eldred.

WEDNESDAY AFTERNOON

On Wednesday afternoon the members visited the Atlas Engine Works, the National Motor Vehicle Company, the Nordyke & Marmon Plant and the Perry Manufacturing Plant. The ladies visited the Eli Lilly Company in the morning, and in the afternoon were taken in automobiles to the Country Club where the Social Committee served tea. Mr. William Rockwood, Chairman of the Committee for the Entertainment of Ladies, and the Indianapolis ladies who assisted, provided most hospitable entertainment.

WEDNESDAY EVENING SESSION

BALL BEARINGS, Henry Hess

Discussed by,

T. J. Fay

AIR COOLING OF AUTOMOBILES ENGINES, John Wilkinson

MATERIALS FOR AUTOMOBILES, Elwood Haynes

RAILWAY MOTOR CARS, B. D. Gray

Discussed by,

Prof. W. F. M. Goss, H. Emerson, William Forsyth, C. D. Young.

[1] This report was not presented for adoption, and therefore is not published in this volume.

THURSDAY MORNING SESSION

THE SPECIFIC HEAT OF SUPERHEATED STEAM, A. R. Dodge

Discussed by,

Prof. S. A. Reeve, Prof. R. C. Carpenter, H. B. Dirks, Prof. W. F. M. Goss, Prof. F. C. Wagner, Prof. D. S. Jacobus, A. H. Kruesi.

THE FLOW OF SUPERHEATED STEAM IN PIPES, E. H. Foster

Discussed by,

F. Koester, H. Webster, Prof. D. S. Jacobus, E. H. Foster, M. E. R. Toltz, A. H. Kruesi.

SUPERHEAT AND FURNACE RELATIONS, R. P. Bolton

Discussed by,

M. E. R. Toltz, J. R. Brown, A. H. Kruesi, H. Webster.

ENTROPY LINES OF SUPERHEATED STEAM, Prof. A. M. Greene

THE COST OF HEATING STORE HOUSES, H. O. Lacount

Discussed by,

Prof. W. D. Ennis, E. N. Trump, W. F. Hendry, J. H. Kinealy

THURSDAY AFTERNOON

The members and ladies attended the unveiling of the Lawton Monument on Thursday afternoon, when President Roosevelt made an address. Special seats had been secured by the Local Committee for the Society and its guests.

THURSDAY EVENING

The formal reception was held in the parlors of the Claypool Hotel when the members and guests were received by President Frederick R. Hutton and Mrs. Hutton, Secretary Calvin W. Rice and Mrs. Rice, Chairman of the Local Committee, J. R. Whittemore and Mrs. Whittemore.

FRIDAY

Friday was spent at Purdue University. The representatives of the University met the visitors at the gate and escorted them to the Chapel where an address of welcome was made by Dr. W. F. M. Goss, Dean of the School of Engineering, Purdue University, to which

President Hutton responded. The last of the professional sessions was held at the University.

At the close of the professional session a delightful luncheon was served in the Agricultural Building after which the visitors were conducted over the grounds, and special visits made to the laboratories. The Locomotive Testing Laboratory was found unusually interesting because of its collection of historic locomotives. A Committee of ladies from the University received the ladies of the party and very graciously provided for their entertainment.

PROFESSIONAL SESSION AT PURDUE

Cole Locomotive Superheaters, Prof. W. F. M. Goss

Discussed by,
H. H. Vaughan, F. J. Cole, A. H. Kruesi.

Experiences with Superheated Steam, G. H. Barrus

Discussed by,
M. E. R. Toltz, A. H. Kruesi, E. H. Foster.

Use of Superheated Steam in an Injector, S. L. Kneass

Superheated Steam on Locomotives, H. H. Vaughan

Discussed by,
M. E. R. Toltz.

Analysis of Locomotive Tests, Prof. S. A. Reeve

Discussed by,
Prof. W. F. M. Goss, Prof. William Kent.

Materials for the Control of Superheated Steam, M. W. Kellogg

Discussed by,
J. R. Brown, A. H. Kruesi, M. E. R. Toltz.

APPENDIX

THE NEW HEADQUARTERS OF THE SOCIETY

The Society moved into its new offices on the eleventh floor of the Engineering Societies Building at 29 West 39th Street, New York, on January 1. The spacious offices afford the room so much needed for the increasing activities of the Society.

The house at 12 West 31st Street, except the Library, was closed at the same time. The Library was moved to the new building on March 1. It occupies, together with the libraries of the American Institute of Electrical Engineers and the American Institute of Mining Engineers the entire twelfth and thirteenth floors; the twelfth floor being used as a stack room, and the thirteenth affording unusual facilities for a reading room by reason of its skylights and broad windows from which a splendid view may be had of the north and south parts of the city, of the East River on the east, and of the Palisades of the Hudson on the west.

ANDRREW CARNEGIE, HONORARY MEMBER

At a meeting of the Council of the Society, April 16, 1907, the following nomination for Honorary Member was presented.

To THE COUNCIL OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

The undersigned members of the Society hereby propose Andrew Carnegie as a candidate for Honorary Membership in The American Society of Mechanical Engineers. In compliance with paragraph C 13 of the Constitution, we present the following grounds for the nomination:

ANDREW CARNEGIE IS THE GREATEST IRONMASTER THE WORLD HAS EVER KNOWN.

[Signed]

E. B. ARCHER
JOHN A. BRASHEAR
JOHN FRITZ
JOHN E. SWEET
THOMAS FITCH ROWLAND
S. T. WELLMAN
CHARLES WALLACE HUNT
CHAS. H. HASWELL
THOMAS A. EDISON
CHARLES H. MORGAN
WORCESTER R. WARNER

As required by the Constitution, election to honorary membership must be without a dissenting vote, and the Council was unanimous in conferring the greatest honor in the power of the Society upon Mr Carnegie.

NEW JUNIOR BADGE

The Membership Committee, with the approval of the Council, has adopted a new badge for the Junior grade of membership. The badge is of the same design and form as the Members' badge, but is crimson instead of blue. The reason for the change is that the old form of Junior badge is unlike the recognized emblem of the Society, and on that account is not satisfactory.

Business Presented and Transacted at the Wednesday Morning, May 29, Session of the Indianapolis Meeting

ELECTIONS TO MEMBERSHIP

The following were declared elected to membership in the Society, upon the ballot of March 30, 1907.

MEMBERS

Bigelow, Frank Burr, Chicago, Ill.
Bocorselski, F. E., Springfield, Mass.
Canniff, W. L., New York.
Carhart, Alfred Bangs, Charlestown, Mass.
Carle, Nathaniel Allen, New York.
Chamberlain, Harry Maynard, Dorchester Center, Mass.
Connon, George William, New York.
Cooke, George William, Buffalo, N. Y.
Delany, Charles Henry, Barberton, Ohio.
Dunbar, James Horace, Cleveland, Ohio.
Elliott, Elmer George, Perth Amboy, N. J.
Farquhar, Francis, York, Pa.
Farrar, Edward, Johannesburg, S. Africa.
Gladding, Wanton Martin, New Bedford, Mass.
Haines, Edward Preston, Columbus, Ohio.
Hecht, Julius Lawrence, Chicago, Ill.
Hinds, Fred Sumner, Boston, Mass.
Humphrey, Orman Brown, Bangor, Me.
Jakobsson, Herman Gustaf, Bethlehem Pa.
Jowett, J. H., New York.
Kiesel, William Frederic, Jr., Altoona, Pa.
Lees, Ernest James, Cleveland, Ohio.
Leland, Frederic H., Mount Vernon, N. Y.
Lighthipe, William Wilson, New York.
Linzee, A. C., Akron, Ohio.
Lombard, Nathaniel, Akron, Ohio.
Luhr, Otto, Chicago, Ill.
Luther, Stephen Grinnell, Buffalo, N.Y.
MacFarland, Helon Brooks, Chicago, Ill.
Merritt, Arthur A., New York.
Moore, Samuel L., Elizabeth N. J.
Pharr, Henry Newton, Olivier, La.
Potter, James C., Pawtucket, R. I.
Rice, Charles DeLos, Hartford, Conn.
Sedgwick, Edward V., Paris, France.
Sherman, Willis Durwood, Brooklyn, N. Y.
Taylor, George W. K., New York.
Warren, Ambrose Gilmore, Philadelphia, Pa.
Warren, Kenneth Loyola, Fraserville, Quebec, Canada.
Whittlesey, James Thomas, Montclair, N. J.

Wright, Reginald Ashmun, Sherbrooke, Quebec.

PROMOTED TO MEMBER

Ball, Fred Ossian, Plainfield, N. J.
Barnes, Eliphalet Austin, Syracuse, N. Y.
Dickerman, Walter Carter, New York.
Holmes, William Grant, Erie, Pa.
Isham, Henry Smyth, New York.
Lockwood, J. Fred., Brooklyn, N. Y.
Matthews, John G., Three Rivers, Mich.
Rumsey, Spencer Smith, Duluth, Minn.
Salter, T. F., Philadelphia, Pa.
Tait, G. M. S., New York.
Thomas, Edward G., Boston, Mass.
Tower, Daniel Webster, Grand Rapids, Mich.
Weymouth, Clarence R., San Francisco, Cal.
Wood, Arthur Julius, State College, Pa.

ASSOCIATES

Brendlinger, William B., New York.
Chase, Leon Wilson, Lincoln, Neb.
Clergue, Bertrand Joseph, Sault Ste Marie, Ontario, Canada.
Davis, Thomas B., Columbus, O.
DeGaigne, Oscar Victor, Worcester, Mass.
Frankenberg, George Theodore, East Columbus, Ohio.
Gay, Harry, Yonkers, N. Y.
Marshall, Stewart McC., Johnstown, Pa.
Moore, Harold T., Philadelphia, Pa.
Ray, Frederick L., New York.
Rogers, Fred E., East Orange, N. J.
Schakel J. D., Yonkers, N. Y.
Stanbrough, D. G., Norfolk, Va.

PROMOTED TO ASSOCIATE GRADE

Upson, Maxwell Mayhew, Rockville, Conn.
Wilson, Lester Godfrey, Norfolk, Va.

JUNIORS

Armstrong, Walter Jonas, Columbus, O.
Arnold, E. B., Milwaukee, Wis.
Bixby, Walter, Hyde Park, Mass.
Bourquin, Jas. T., Detroit, Mich.
Brooks, J. Ansel, Providence, R. I.
Coale, Harvey M., Ardmore, Pa.
Crofoot, Geo. Emerson, Phila., Pa.
Cunningham, Robt. H., Jr., New York.
Danks, Alfred C., Pittsburg, Pa.
Dean, Arthur, M., Hagerstown, Md.
Dirks, Henry Bernard, Urbana, Ill.
Doud, Arthur T., New York.
Duden, Emil Gustave, Oakmont, Pa.
Dunn, H. A., East Orange, N. J.
Feicht, Edward R., Dayton, O.
Fisher, H. D., Philadelphia, Pa.
Fowler, S. D., State College, Pa.
Fraser, David Ross, Chicago, Ill.
Greenman, Edwin G., Cincinnati, O.
Griswold, Roger W., Erie, Pa.
Hackstaff, F. W., New York.
Johnson, David C., Brooklyn, N. Y.
Lucker, G. C., Brooklyn, N. Y.
McLean, Robt. W., Boston, Mass.
Macintire, Horace J., Boston, Mass.
Magee, John, Hamilton, Montana.
Manley, Sumner M., Kansas City, Kan.
Pettengill, Geo. D. Warsaw, N. Y.
Pinger, Geo. C., Warren, Pa.
Read, Geo. F., Jr., Fall River, Mass.
Reno, Harold P., Saylesville, R. I.
Roys, Lawrence, Three Rivers, Mich.
Wilson, Geo. S., Seattle, Washington.

SUMMARY

Election to full membership	41
Election to Associate grade	13
Election to Junior grade	33
Promotion to Member grade	14
Promotion to Associate grade	2
Total number declared elected	103

AMENDMENT TO BY-LAW 36

To conform with C59, the following amendment to B36 was voted by the Council to take effect immediately.

Ballots for an amendment to the Constitution shall be canvassed and announced in the same manner as the ballots for officers of the Society. The President shall appoint three Tellers to canvass any letter ballots which shall be ordered by the Council or by the Society and to certify the same to the President.

AMENDMENTS TO THE CONSTITUTION

The following amendments to C38 and C45 of the Constitution were presented to the Membership as provided by Section 57, voted upon, and passed by the ballot closing March 4.

AMENDMENT NO. 1

To add to the end of Section C38 the following:

The Council may also in its discretion appoint a person of the grade of Member to be an Honorary Secretary of the Society for a term not to exceed one year, but he may be reappointed from year to year. He shall perform such duties as may be assigned to him by the Council which are in conformity with the Constitution and By-Laws, and with or without compensation as the Council may direct.

AMENDMENT NO. 2

To add to Article C45 after the words:

"House Committee" the words "Research Committee."

The membership is hereby notified of these amendments.

No. 1142

STANDARD PROPORTIONS FOR MACHINE SCREWS

Revised Report of the Committee on Standard Proportions for Machine Screws

To The American Society of Mechanical Engineers:

Having considered the suggestions which have been made since the original report was presented at the New York Meeting, in December, 1905, your Committee now has the honor to present the following amended report.

2 It has been found advisable to change, except in three instances, the nominal outside diameters for the standard sizes of machine screws, and to include in this new list certain additional sizes. The change in the sizes originally proposed varies only from 0.001 inch to 0.003 inch, and avoids an impracticable degree of departure from the already established screw gage diameters.

3 The Standard Diameters for Machine Screws shall be the 21 sizes given in Table 1.

4 The included angle of the thread shall be 60 degrees, with flat at top and bottom of the thread for the basic standard of one-eighth of the pitch, as originally recommended.

5 The uniform increment between all sizes from 0.060 inch to 0.190 inch is 0.013 inch, and between 0.190 inch and including 0.450 inch is 0.026 inch. This conforms approximately to the list of screw gage sizes originally established, in which the increment in 0.01316 inch.

6 This evidently avoids impracticable final decimals, and forms a series in which the sizes have a definite relation to each other.

7 Your Committee has also thought it advisable to make this change, not only in the interest of simplicity and the use of fewer significant figures, but also because the resulting pitch diameters are more nearly in accord with the pitch diameters of machine screws in present use.

This final Report of the Committee on Standard Proportions for Machine Screws was accepted at the Indianapolis Meeting (May 1907), of The American Society of Mechanical Engineers, and forms part of Volume 29 of the Transactions.

TABLE 1 STANDARD MACHINE SCREWS

Basic and Maximum Screw Diameters			Minimum Screw Diameters		
External diam. and No. thds. per in.	Pitch diameter	Root diameter	External diameter	Pitch diameter	Root diameter
.060—80	.0519	.0438	.0572	.0505	.0410
.073—72	.0640	.0550	.0700	.0625	.0520
.086—64	.0759	.0657	.0828	.0743	.0624
.099—56	.0874	.0758	.0955	.0857	.0721
.112—48	.0985	.0849	.1082	.0966	.0807
.125—44	.1102	.0955	.1210	.1082	.0910
.138—40	.1218	.1055	.1338	.1197	.1007
.151—36	.1330	.1149	.1466	.1308	.1097
.164—36	.1460	.1279	.1596	.1438	.1227
.177—32	.1567	.1364	.1723	.1544	.1307
.190—30	.1684	.1467	.1852	.1660	.1407
.216—28	.1928	.1696	.2111	.1904	.1633
.242—24	.2149	.1879	.2368	.2123	.1808
.268—22	.2385	.2090	.2626	.2358	.2014
.294—20	.2615	.2290	.2884	.2587	.2208
.320—20	.2875	.2550	.3144	.2847	.2468
346—18	.3099	.2738	.3402	.3070	.2649
.372—16	.3314	.2908	.3660	.3284	.2810
.398—16	.3574	.3168	.3920	.3544	.3070
.424—14	.3776	.3312	.4178	.3745	.3204
.450—14	.4036	.3572	.4438	.4005	.3464

8 The pitches are a function of the diameter, as expressed by the formula,

$$\text{threads per inch} = \frac{6.5}{D + 0.02}$$

and the results are given approximately and in even numbers in order to avoid the use of fractional or odd number threads.

9 In recommending certain limits for variation from the basic standard, the maximum screw shall conform practically in all respects to the basic standards. The minimum screw shall have a flat at bottom of the thread of one-sixteenth of the pitch and the difference between the maximum and the minimum root diameter will allow at bottom of the thread any width of flat between one-sixteenth and one-eighth of the pitch, thus providing allowance for variation. See diagram, Fig. 1.

10 The maximum tap shall have a flat at top of the thread equal to one-sixteenth of the pitch and the difference between maximum and minimum external diameter will allow at the top of thread of tap any width of flat between one-sixteenth and one-eighth of the pitch.

TABLE 1 STANDARD MACHINE SCREWS

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.086—64	.0759	.0657	.0828	.0743	.0624
.099—56	.0874	.0758	.0955	.0857	.0721
.112—48	.0985	.0849	.1082	.0966	.0807
.125—44	.1102	.0955	.1210	.1082	.0910
.138—40	.1218	.1055	.1338	.1197	.1007
.151—36	.1330	.1149	.1466	.1308	.1097
.164—36	.1460	.1279	.1596	.1438	.1227
.177—32	.1567	.1364	.1723	.1544	.1307
.190—30	.1684	.1467	.1852	.1660	.1407
.216—28	.1928	.1696	.2111	.1904	.1633
.242—24	.2149	.1879	.2368	.2123	.1808
.268—22	.2385	.2090	.2626	.2358	.2014
.294—20	.2615	.2290	.2884	.2587	.2208
.320—20	.2875	.2550	.3144	.2847	.2468
346—18	.3099	.2738	.3402	.3070	.2649
.372—16	.3314	.2908	.3660	.3284	.2810
.398—16	.3574	.3168	.3920	.3544	.3070
.424—14	.3776	.3312	.4178	.3745	.3204
.450—14	.4036	.3572	.4438	.4005	.3464

8 The pitches are a function of the diameter, as expressed by the formula,

$$\text{threads per inch} = \frac{6.5}{D + 0.02}$$

and the results are given approximately and in even numbers in order to avoid the use of fractional or odd number threads.

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10 The maximum tap shall have a flat at top of the thread equal to one-sixteenth of the pitch and the difference between maximum and minimum external diameter will allow at the top of thread of tap any width of flat between one-sixteenth and one-eighth of the pitch.

11 The minimum tap shall conform to the basic standard in all respects except diameter, as clearly shown by the diagram Fig. 1.

12 The difference between the minimum tap and the maximum screw provides an allowance for error in pitch, or lead, and for the wear of tap in service.

13 The form of tap thread shown in the diagram is recommended as being stronger and more serviceable than the so-called V thread, but it has been suggested that strict adherence to the form shown might, in the case of small taps, add to their cost.

14 Your Committee would say, however, that taps with V threads and with the correct angle and pitch diameters used in connection with tap drills of correct diameter, are permissible. This will also utilize a large proportion of the V thread taps now in stock.

TABLE 2

FORMULAS FOR PROPOSED STANDARD FOR MACHINE SCREWS AND TAPS. BASIC STANDARD THREAD, U. S. FORM

SCREWS

Max. external diam.	= basic external diam.	
Max. pitch diam.	= basic pitch diam.	
Max. root diam.	= basic root diam.	
Min. external diam.	= basic external diam.	$- \dfrac{.336}{\text{T.P.I.}+40}$
Min. pitch diam.	= basic pitch diam.	$- \dfrac{.168}{\text{T.P.I.}+40}$
Min. root diam.	= basic root diam.	$- \left[\dfrac{.10825}{\text{T.P.I.}} + \dfrac{.168}{\text{T.P.I.}+40}\right]$

TAPS

Max. external diam.	= basic external diam.	$+ \dfrac{.10825}{\text{T.P.I.}} + \dfrac{.224}{\text{T.P.I.}+40}$
Max. pitch diam.	= basic pitch diam.	$+ \dfrac{.224}{\text{T.P.I.}+40}$
Max. root diam.	= basic root diam.	$+ \dfrac{.336}{\text{T.P.I.}+40}$
Min. external diam.	= basic external diam.	$+ \dfrac{.112}{\text{T.P.I.}+40}$
Min. pitch diam.	= basic pitch diam.	$+ \dfrac{.112}{\text{T.P.I.}+40}$
Min. root diam.	= basic root diam.	$+ \dfrac{.112}{\text{T.P.I.}+40}$

Note – T. P. I. = threads per inch.

TABLE 3

PROPOSED STANDARD OF MACHINE SCREWS

DIFFERENCES BETWEEN MAXIMUM AND MINIMUM DIAMETERS

Threads per inch	External	Pitch	Root
80	.0028	.0014	.0028
72	.0030	.0015	.0030
64	.0032	.0016	.0033
56	.0035	.0017	.0037
48	.0038	.0019	.0042
44	.0040	.0020	.0045
40	.0042	.0021	.0048
36	.0044	.0022	.0052
32	.0047	.0023	.0057
30	.0048	.0024	.0060
28	.0049	.0024	.0063
24	.0052	.0026	.0071
22	.0054	.0027	.0076
20	.0056	.0028	.0082
18	.0058	.0029	.0089
16	.0060	.0030	.0098
14	.0062	.0031	.0108
Formulae	$\frac{.336}{\text{T.P.I.} + 40}$	$\frac{.168}{\text{T.P.I.}+40}$	$\frac{.10825}{\text{T.P.I.}} + \frac{.168}{\text{T.P.I.}+40}$
Note—T.P.I. = threads per inch.			

STANDARD REFERENCE THREAD GAGES

15 Your Committee again recommends the use of standard ref(ence thread gages for establishing the basic outside and pitch dian ters, with flat at top and bottom of the thread of one-eighth of t pitch, to represent exactly in every detail, the data required 1 maintaining the standard machine screw sizes here submitted.

16 The reference thread gages include also reference thread gag for screws and reference thread gages for taps, each of these represe the limiting diameters and details for the maximum and minimu allowance, as compared with the basic standard reference thre gages.

17 These gages are represented by Fig. 2, 3, and 4, respective and are to be made of unhardened steel, of 0.35 per cent carbon, pl gages only, as originally recommended by your Committee in 19(

LIMITS OF VARIATION IN SCREW AND TAP DIAMETERS

18 In carrying out the principle of simplification, your Committee presents herewith revised formulae for determining the limits of variation found practical for screw and tap diameters. These

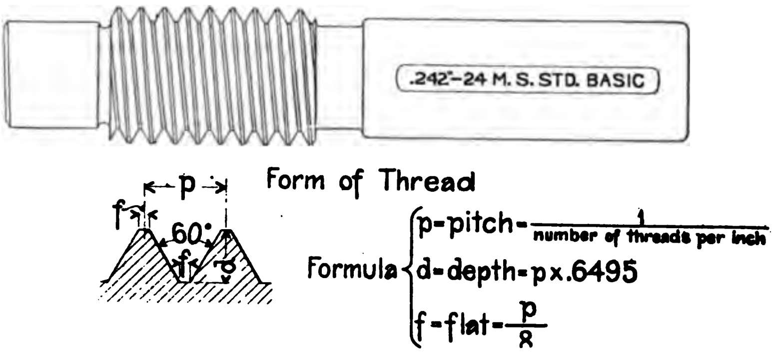


FIG. 2 BASIC STANDARD REFERENCE THREAD GAGE

TABLE 4 TAPS

Size and no. thds. per inch	Minimum			Maximum		
	External diameter	Pitch diameter	Root diameter	External diameter	Pitch diameter	Root diameter
.060—80	.0609	.0528	.0447	.0632	.0538	.0466
.073—72	.0740	.0650	.0560	.0765	.0660	.0580
.086—64	.0871	.0770	.0668	.0898	.0781	.0689
.099—56	.1002	.0886	.0770	.1033	.0897	.0793
.112—48	.1133	.0998	.0862	.1168	.1010	.0887
.125—44	.1263	.1116	.0968	.1301	.1129	.0995
.138—40	.1394	.1232	.1069	.1435	.1246	.1097
.151—36	.1525	.1345	.1164	.1569	.1359	.1193
.164—36	.1655	.1475	.1294	.1699	.1489	.1323
.177—32	.1786	.1583	.1380	.1835	.1598	.1411
.190—30	.1916	.1700	.1483	.1968	.1716	.1515
.216—28	.2176	.1944	.1712	.2232	.1961	.1745
.242—24	.2438	.2167	.1896	.2500	.2184	.1931
.268—22	.2698	.2403	.2108	.2765	.2421	.2144
.294—20	.2959	.2634	.2309	.3031	.2652	.2346
.320—20	.3219	.2894	.2569	.3291	.2912	.2606
.346—18	.3479	.3118	.2757	.3559	.3138	.2796
.372—16	.3740	.3334	.2928	.3828	.3354	.2968
.398—16	.4000	.3594	.3188	.4088	.3614	.3228
.424—14	.4261	.3797	.3333	.4359	.3818	.3374
.450—14	.4521	.4057	.3593	.4619	.4078	.3634

formulae for screws include maximum and minimum external, root, and pitch diameters, and are given in Table 2.

19 The limits for screws for each pitch are given in Table 3, and are the amounts less than basic standard for minimum screws, the maximum limit being standard.

TABLE 5

EXCESS OF TAP DIAMETER OVER BASIC DIAMETER BASED UPON EACH PITCH OF THREAD RECOMMENDED

Threads per inch	Excess of min. external, pitch and root diam. over basic	Excess of max. external diam. over basic	Excess of max. pitch diam. over basic	Excess of max. root diam. over basic
80	.0009	.0032	.0019	.0028
72	.0010	.0035	.0020	.0030
64	.0011	.0038	.0022	.0032
56	.0012	.0043	.0023	.0035
48	.0013	.0048	.0025	.0038
44	.0013	.0051	.0027	.0040
40	.0014	.0055	.0028	.0042
36	.0015	.0059	.0029	.0044
32	.0016	.0065	.0031	.0047
30	.0016	.0068	.0032	.0048
28	.0016	.0072	.0033	.0049
24	.0018	.0080	.0035	.0053
22	.0018	.0085	.0036	.0054
20	.0019	.0091	.0037	.0056
18	.0019	.0099	.0039	.0058
16	.0020	.0108	.0040	.0060
14	.0021	.0119	.0042	.0062
	Formula = $\frac{.112}{T.P.I.+40}$	Formula = $\frac{.10825}{T.P.I.}+\frac{.224}{T.P.I.+40}$	Formula = $\frac{.224}{T.P.I.+40}$	Formula = $\frac{.336}{T.P.I.+40}$

Note—T. P. I.=threads per inch.

Note—The formulae given are expressed in terms of *threads per inch* instead of pitch, thus avoiding the use of the reciprocal of each, which obviously involves a greater number of decimals.

20 The diameters recommended for limits for taps are also given herewith, and comprise the maximum and minimum external, root, and pitch diameters. See Table 4. Table 5 shows the excess of tap diameter over that of basic standard.

These formulae also provide a limit to allow for variation of pitch as well as for the diameter of screw and taps.

21 Your Committee desires to state again that the screws here considered are those known as pressed head machine screws; are manufactured in great quantities, and are listed and sold to the trade by the gross. These formulae however, apply equally well to the

TABLE 6 SPECIAL SIZES
SCREWS

Basic and Maximum Screw Diameters			Minimum Screw Diameters		
External dia. and no. of thds. per inch	Pitch diameter	Root diameter	External diameter	Pitch diameter	Root diameter
.073—64	.0629	.0527	.0698	.0613	.0494
.086—56	.0744	.0628	.0825	.0727	.0591
.099—48	.0855	.0719	.0952	.0836	.0677
.112—40	.0958	.0795	.1078	.0937	.0747
—36	.0940	.0759	.1076	.0918	.0707
.125—40	.1088	.0925	.1208	.1067	.0877
—36	.1070	.0889	.1206	.1048	.0837
.138—36	.1200	.1019	.1336	.1178	.0967
—32	.1177	.0974	.1333	.1154	.0917
.151—32	.1307	.1104	.1463	.1284	.1047
—30	.1294	.1077	.1462	.1270	.1017
.164—32	.1437	.1234	.1593	.1414	.1177
—30	.1424	.1207	.1592	.1400	.1147
.177—30	.1553	.1337	.1722	.1529	.1277
—24	.1499	.1229	.1718	.1473	.1158
.190—32	.1697	.1494	.1853	.1674	.1437
—24	.1629	.1359	.1848	.1603	.1288
.216—24	.1889	.1619	.2108	.1863	.1548
.242—20	.2095	.1770	.2364	.2067	.1688
.268—20	.2355	.2030	.2624	.2327	.1948
.294—18	.2579	.2218	.2882	.2550	.2129
.320—18	.2839	.2478	.3142	.2810	.2389
.346—16	.3054	.2648	.3400	.3024	.2550
.372—18	.3359	.2998	.3662	.3330	.2909
.398—14	.3516	.3052	.3918	.3485	.2944
.424—16	.3834	.3428	.4180	.3804	.3330
.450—16	.4094	.3688	.4440	.4064	.3590

diameter of corresponding sizes if made by machine operation from stock which is the diameter of the required head. The formulae for heads given in your Committee's report, are for pressed head screws only.

22 In reference to the discussion of the original report of your Committee relative to heads of machine screws having a flat top and upper corners rounded, this has been carefully considered, but your Committee has been unable to find in any published lists of the manufacturers of machine screws of the character covered by this report

26 The threads of these templet gages to be made by taps having the thread enough larger than standard in outside diameter to insure clearance at the top of the thread of the screw.

27 In addition to the threaded or tapped holes, these gages should have plain cylindrical holes representing, respectively, the external diameter of the maximum and minimum screw.

TABLE 9 TAP DRILL DIAMETERS, STANDARD

.060—80	.0465	.216—28	.1730
.073—72	.0595	.242—24	.1935
.086—64	.0700	.268—22	.2130
.099—56	.0785	.294—20	.2340
.112—48	.0890	.320—20	2610
.125—44	.0995	.346—18	.2810
.138—40	.1100	.372—16	.2968
.151—36	.1200	.398—16	.3230
.164—36	.1360	.424—14	.3390
.177—32	.1405	.450—14	.3680
.190—30	.1520		

28 These templet gages are designed to admit at the maximum end all screws that are within the limits, and to reject all screws that are larger, while screws smaller than the minimum end of the templet

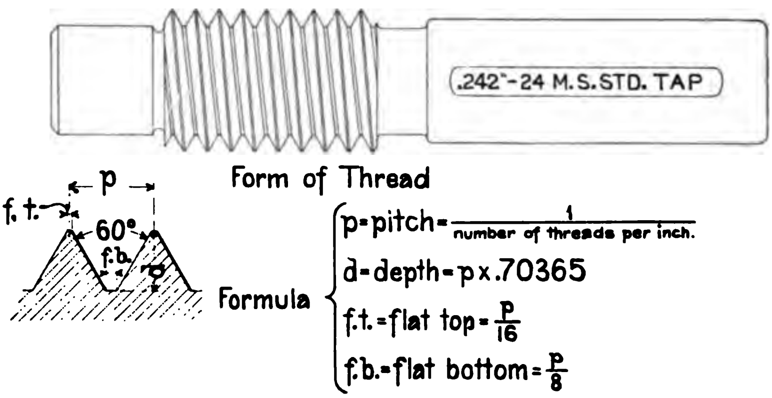


FIG. 4 REFERENCE THREAD GAGES FOR TAPS

gage are thus shown to be less in diameter than is specified by the minimum limit recommended by your Committee.

29 For the convenience of users of machine screws and taps, Table 9 is here inserted, giving the diameter of drills for holes to be

tapped for the standard machine screws covered by this report, and also Table 10, for taps included in the list of special sizes and pitches shown in Table 6. The diameter given for each hole to be tapped allows for a practical clearance at the root of the thread of the screw and will not impose undue strain upon the tap in service.

HEADS FOR STANDARD MACHINE SCREWS

30 Certain changes have been made necessary in the tables for the dimensions of heads for standard machine screws, due to the

TABLE 10 TAP DRILL DIAMETERS, SPECIAL

.073—64	.0550	—24	.1285
.086—56	.0670	.190—32	.1540
.099—48	.0760	—24	.1405
.112—40	.0820	.216—24	.1660
—36	.0810	.242—20	.1820
.125—40	.0980	.268—20	.2090
—36	.0935	.294—18	.2280
.138—36	.1065	.320—18	.2570
—32	.1015	.346—16	.2720
.151—32	.1160	.372—18	.3125
—30	.1130	.398—14	.3125
.164—32	.1285	.424—16	.3480
—30	.1285	.450—16	.3770
.177—30	.1405		

difference in body diameters, as compared with the list as originally submitted, and are given in Tables 11, 12, 13, and 14. The formulae for the details are given with each table, with the type of each style of head accompanying.

31 The list of heads comprises flat, round, flat fillister head, and oval fillister head screws.

32 Flat head screws have an included angle of 82 degrees, which is a maximum angle for this style head, but a reduction of this angle of not more than one or two degrees, due to the wear of tools in their manufacture, may be tolerated.

33 Round heads, so called, are, however, in axial cross section, a semi-ellipse, hence formulae B and C cover all the practical details for determining their form.

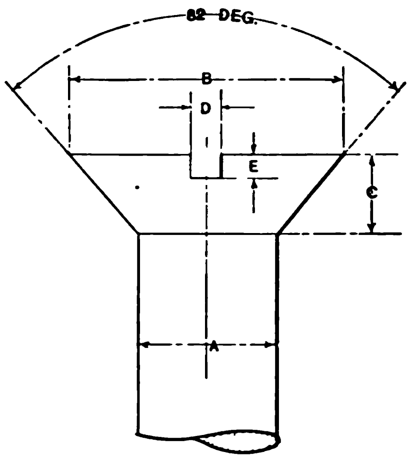


TABLE 11 FLAT HEAD SCREWS

A = diameter of body
B = 2A − .008 = diameter of head
$C = \frac{A - .008}{1.739}$ = thickness of head
D = .173A + .015 = width of slot
E = ¾C = depth of slot

A	B	C	D	E
.060	.112	.030	.025	.010
.073	.138	.037	.028	.012
.086	.164	.045	.030	.015
.099	.190	.052	.032	.017
.112	.216	.060	.034	.020
.125	.242	.067	.037	.022
.138	.268	.075	.039	.025
.151	.294	.082	.041	.027
.164	.320	.090	.043	.030
.177	.346	.097	.046	.032
.190	.372	.105	.048	.035
.216	.424	.120	.052	.040
.242	.476	.135	.057	.045
.268	.528	.150	.061	.050
.294	.580	.164	.066	.055
.320	.632	.179	.070	.060
.346	.684	.194	.075	.065
.372	.736	.209	.079	.070
.398	.788	.224	.084	.075
.424	.840	.239	.088	.080
.450	.892	.254	.093	.085

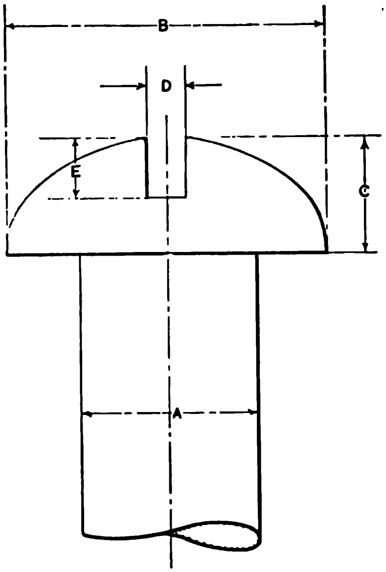


TABLE 12 ROUND HEAD SCREWS

A = diam. of body
B = 1.85A − .005 = diam. of head
C = .7A = height of head
D = .173A + .015 = width of slot
E = ½C + .01 = depth of slot

A	B	C	D	E
.060	.106	.042	.025	.031
.073	.130	.051	.028	.035
.086	.154	.060	.030	.040
.099	.178	.069	.032	.044
.112	.202	.078	.034	.049
.125	.226	.087	.037	.053
.138	.250	.097	.039	.058
.151	.274	.106	.041	.063
.164	.298	.115	.043	.067
.177	.322	.124	.046	.072
.190	.346	.133	.048	.076
.216	.394	.151	.052	.085
.242	.443	.169	.057	.094
.268	.491	.188	.061	.104
.294	.539	.206	.066	113
.320	.587	.224	.070	.122
.346	.635	.242	.075	.131
.372	.683	.260	.079	.140
.398	.731	.279	.084	.149
.424	.779	.297	.088	.158
.450	.827	.315	.093	.167

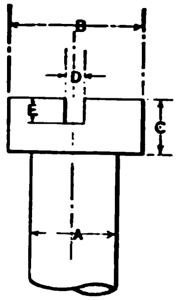


TABLE 13 FLAT FILLISTER HEAD SCREWS

A = diam. of body
B = 1.64A − .009 = diam. of head
C = .66A − .002 = height of head
D = .173A + .015 = width of slot
E = ½C = depth of slot

A	B	C	D	E
.060	.0894	.0376	.025	.019
.073	.1107	.0461	.028	.023
.086	.1320	.0548	.030	.027
.099	.1530	.0633	.032	.032
.112	.1747	.0719	.034	.036
.125	.1960	.0805	.037	.040
.138	.2170	.0890	.039	.044
.151	.2386	.0976	.041	.049
.164	.2599	.1062	.043	.053
.177	.2813	.1148	.046	.057
.190	.3026	.1234	.048	.062
.216	.3452	.1405	.052	.070
.242	.3879	.1577	.057	.079
.268	.4305	.1748	.061	.087
.294	.4731	.1920	.066	.096
.320	.5158	.2092	.070	.104
.346	.5584	.2263	.075	.113
.372	.6010	.2435	.079	.122
.398	.6437	.2606	.084	.130
.424	.6863	.2778	.088	.139
.450	.7290	.2950	.093	.147

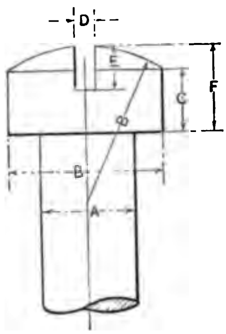


TABLE 14 OVAL FILLISTER HEAD SCREWS

A = diameter of body
B = 1.64A − .009 = diam. of head and rad. for oval
C = 0.66A − .002 = height of side
D = .173A + .015 = width of slot
E = ½F = depth of slot
F = .134B + C = height of head

A	B	C	D	E	F
.060	.0894	.0376	.025	.025	.0496
.073	.1107	.0461	.028	.030	.0609
.086	.1320	.0548	.030	.036	.0725
.099	.1530	.0633	.032	.042	.0838
.112	.1747	.0719	.034	.048	.0953
.125	.1960	.0805	.037	.053	.1068
.138	.2170	.0890	.039	.059	.1180
.151	.2386	.0976	.041	.065	.1296
.164	.2599	.1062	.043	.071	.1410
.177	.2813	.1148	.046	.076	.1524
.190	.3026	.1234	.048	.082	.1639
.216	.3452	.1405	.052	.093	.1868
.242	.3879	.1577	.057	.105	.2097
.268	.4305	.1748	.061	.116	.2325
.294	.4731	.1920	.066	.128	.2554
.320	.5158	.2092	.070	.140	.2783
.346	.5584	.2263	.075	.150	.3011
.372	.6010	.2435	.079	.162	.3240
.398	.6437	.2606	.084	.173	.3469
.424	.6863	.2778	.088	.185	.3698
.450	.7290	.2950	.093	.196	.3927

34 It is believed by your Committee that the use of the formulae and resulting tables here given will insure the practical interchangeability of the class of machine screws covered by this report.

Respectfully submitted:

WILFRED LEWIS, *Chairman.*
CHARLES C. TYLER,
HORACE K. JONES,
JOHN RIDDELL,
GEORGE R. STETSON.
GEORGE M. BOND.

HISTORY OF THE COMMITTEE

35 The Committee was appointed to consider and report on the question of Standard Proportions for Machine Screws as the result of a resolution passed at the Boston Meeting in 1902, following a paper presented by Mr. Charles C. Tyler at that meeting and the discussion brought out by it.

36 The Committee's first Report was presented at the Annual Meeting in New York, December 1905, where it was discussed and, as a result, amended and again presented at the Chattanooga Meeting in May 1906. After some further changes it was again presented and discussed at the Annual Meeting held in New York in December of the same year and in its final revised form was presented and by unanimous vote of the Society, accepted at the Indianapolis meeting in May 1907.

37 It is not thought advisable to print in the Transactions all the preliminary reports and of course much of the discussion upon them would not be pertinent to the report as finally adopted. During the period of over three years in which the Committee had the seemingly small but really large and important matter of the standardization of machine screws under consideration, they were assisted in arriving at a satisfactory conclusion by various manufacturers making and using machine screws and taps and dies therefor and, so far as the records before the Publication Committee show, by the suggestions and discussions of the Members named below.

38 Edgar H. Berry suggested modifications of the form of the thread proposed; particularly as respects the amount of flattening at the top and bottom. He favored the adoption of the U. S. Standard form of thread.

39 L. D. Burlingame suggested flattening the tops of the threads $\frac{1}{8}$ of the pitch for the smaller sizes of the screws and $\frac{1}{12}$ of the pitch for the larger sizes instead of $\frac{1}{8}$ for all sizes, as had been proposed; recommended a greater allowance of diameter between screws and the corresponding taps than at first proposed; the adoption of a series of screws having threads of finer pitches than those in common use as being more suitable for use in machine tool construction; suggested improvements in the proportions and forms of screw heads; the adoption of sizes already in use and standardized by the American Screw Company, or, if that were not practicable, then the adoption of an entirely new list having sizes in regular increment progression; the adoption of fractional sizes to avoid the confusion of mixing taps and dies of different systems; the adoption of a system of gaging, doing away with

the use of the ball-ended micrometers; slots to conform to the slotting saws already on the market and in general use.

40 G. A. Gulowsen recommended the entire abandonment of special series of sizes and of special forms of threads for machine screws and in their stead the addition of 16 or 17 sizes of suitable diameters down to $\frac{1}{32}$ in. to the present list of U. S. Standard threads for bolts; a system of reference and limit gages which he fully described and illustrated.

41 Fred J. Miller suggested the adoption of a flat or counter sunk head having a rounded corner as being neater and more in harmony with modern ideas in finishing the ends of shafts, etc.

42 Sanford A. Moss advised the adoption of a series continuous with the U. S. Standard screw threads for bolts.

43 E. H. Neff presented objections to adding an entirely new list of sizes and advised the standardization of sizes already in more or less general use; objected to what he considered to be unnecessary and inappropriate refinement in tabulating dimensions of screws as arrived at by the use of specified formulae and to the use of spherical contact surfaces on micrometers used in measuring the sizes of screw threads instead of V surfaces made to fit the threads.

44 Oberlin Smith objected to the proposed "mixing up of truncatings of $\frac{1}{16}$ and $\frac{1}{8}$ the pitch, considering it to be an unnecessary refinement and one not likely to be followed by manufacturers; to the lack of regularity in the increment of sizes throughout the series; to the proposed use of spherical-ended micrometer screws for measuring thread diameters; favored the 80 deg. angle for the heads of flat headed screws and objected to specifying new widths of slots. Incidentally he remarked that, "As a matter of fact, the statement sometimes made that all the U. S. threads are too coarse is not true—for who of us has not been more bothered with stripped threads than broken bolts, especially after the nuts have worn loose, or in cases where the makers have carelessly made them loose."

45 John W. Upp advised the adoption of 80 deg. as the angle for the heads of flat headed screws instead of 82 deg. as had been proposed; the reduction of the size of the heads of the larger screws to $1\frac{3}{4}$ times the diameter of the body; the adoption of a modified form of fillister head screw with the head having a rounded corner; the use of a distinctive mark for the screws to be adopted and widths of slots to conform to the thicknesses of commercial slotting saws.

46 D. A. Wallace advised the adoption of a compromise standard from screws already in use rather than the adoption of an entirely new system; larger allowances of variation; the dropping of needless

refinement in specifying dimensions of screws in very small fractions of an inch instead of leaving this to be done by manufacturers, each according to his own idea; the adoption of slots in conformity with commercial slotting saws; deeper slots and the 80 deg. angle for flat heads.

47 Upon the occasion of the presentation of the final Report Mr. H. K. Jones of the Committee said: Your Committee in this report has aimed to simplify and standardize the present machine screw gage rather than introduce a new one embodying radical changes. In this it has followed the course adopted by your Committee on Pipe Threads of which our Mr. George M. Bond was a member some years ago. In that case the Committee, after careful consideration, selected and made practical application of the original Briggs figures and formulae. The result was a complete acceptance of their recommendation by the makers of Pipe and Pipe Fittings and a very great benefit to the people of the United States.

48 The present machine screw gage is numbered consecutively from 0 to 30, 0 having an outside diameter of 0.05784 with a uniform increment of 0.01316 between the sizes and an outside diameter for 30 of 0.45264—five decimal places for each increment. This gage is in use for both machine and wood screws. For machine screws all odd numbers above 10 are omitted. Many of the makers of screw gage sizes of machine screws are also large makers of wood screws.

49 Practically all of these screws are made of blanks with upset heads and usually of wire which approximates the outside diameters of wood screws.

50 It is quite important to these makers that the machine screws may be made from the same size blank as the wood screw.

51 Your Committee finds a great variation in form and depth of threads in the present so called standards for machine screws, the resulting flat at the top of the thread varying from $\frac{1}{16}$ to more than $\frac{1}{4}$ of the pitch. The pitch diameters are proportionally very large for the small screws, and small for the large ones. Your Committee recommends making outside diameters 0.060 of the old 0, and 0.450 of the old 30, with a uniform increment of 0.013 and the "Sellers" or U. S. form of thread. This brings the proposed pitch diameters nearer the present practice than any other system your Committee has been able to devise. Of course there are some differences that are irreconcilable. That, however, is not the fault of the proposed standard but of the old one. The allowance for variation in outside diameters will permit the use of the same wire as at present in nearly, if not all cases. A liberal allowance for variation in outside diameters is very important

to the makers of machine screws, as it enables them to devote more attention to pitch diameter, which is the most important thing.

52 The diagram and tables show a liberal allowance for clearance and variation at top and bottom of thread without allowing undue variation from the pitch diameters resulting from the use of U. S. form of thread.

53 In the matter of heads, your Committee has simply standardized the present practice of the largest makers. The table for tap drill sizes has been selected from the trade lists of the twist drill makers, and as the intervals between their sizes are irregular there is, in some cases, considerable variation between the listed diameter of the drills and the maximum root diameter of taps. It should be borne in mind that a drill usually makes a hole larger than itself.

54 The present time is certainly opportune for adopting the proposed standard for machine screws. Owing to the unprecedented demand for nearly all kinds of goods the stock of old screws is largely reduced, hence the change should be made before increased facilities cause another accumulation.

55 A large proportion of the makers of machine screws and taps are heartily in favor of this proposed standard and are ready to adopt it, if favorably acted upon by this Society.

56 Professor Jacobus expressed himself as being strongly in favor of accepting the Report as being the best in all probability, to which agreement would be made.

Mr. J. M. Carpenter said:

57 While I am now a new member, I am here as a representative of the J. M. Carpenter Company; I am here also as the representative of various manufacturers of taps and dies whose combined production is more than 90 per cent of the taps and dies produced in this country.

58 Our company has been putting machine taps on the market for 35 years and ours was the first company to do this commercially; hence I have gone through all the tribulations, vexations and troubles arising in every way with the growth of this business and as a result of that experience, I am, to an extent, in a position to judge what this means to the tap and die manufacturers, as well as what it means to the screw manufacturers. As the representative of these tap and die makers for the past year and a half, I have been in close touch with the work of your Committee, and I am free to say that from the knowledge and experience I have gained during that time with the action of your Committee I am fully satisfied that when we take into consideration what has gone before; the condition of the market, the fact that there are hundreds of millions of machine screws consumed

their work the United States standards for pitch of threads have been too coarse, and the dimensions of heads and nuts too large. In order to secure satisfactory construction special fine pitch screw threads and smaller nuts have had to be made.

"It is assumed that where screws are to be used in soft material, such as cast iron, brass, bronze or aluminum, the existing United States standard pitches will be used. The term 'screw' is intended to supplant the present so called 'coupling bolt' and 'cap screw.' The term 'plain hexagon nut' is intended to supplant the present so called 'United States standard nut.' The term 'castle nut' is given to a new nut, which is intended to be used where a positive locking system is desired. The term 'facing' is given to a relieved portion under the screw heads, castle nuts and plain nuts."

The detailed dimensions and specifications of the screws, castle and plain nuts recommended, from ¼ in. to 1 in. inclusive, are shown in the cuts published in the "Bulletin."

This report is accompanied by the following specifications:

MATERIAL

"A better material than ordinarily used for screws is deemed necessary. The selection of a better material depends to a considerable extent upon the possibility of commercially machining it in screw machines. Such material has been found in several qualities of steel having a tensile strength of not less than one hundred thousand (100,000 lb.) pounds per square inch, and an elastic limit of sixty thousand (60,000 lb.) pounds per square inch, as compared with fifty or sixty thousand (50,000 or 60,000 lb.) pounds per square inch tensile strength and thirty-five thousand (35,000 lb.) pounds per square inch elastic limit now in common use. The screws and nuts described in this standard are to be made of this better material. Screws are to be left soft. Screw heads are to be left soft. The plain nuts are to be left soft. The castle nuts are to be case hardened.

TOLERANCE

"The body diameter of the screws shall be one-thousandth (0.001) inch less than the nominal diameter, with a plus tolerance of zero and a minus tolerance of two-thousandths (0.002) inch. The nuts shall be a good fit, without perceptible shake. The clearance between tops of threads and bottoms of threads in nuts shall be that existing in the present practice of machine screw makers; that is, the tap shall be between two-thousandths (0.002) inch and three-thousandths (0.003) inch large.

LENGTH OF THREADED PORTION

The threaded portion of screws shall be one and one-half ($1\frac{1}{2}$) the body diameters.

Fig. 1 and Table 1 following give in summarized form details as to the screws and nuts:

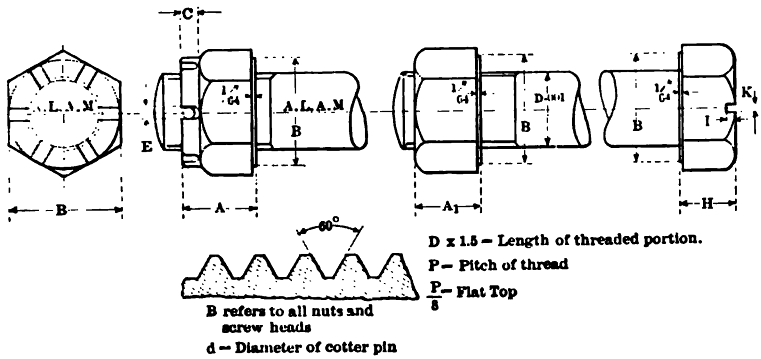


FIG. 1 DETAILS OF SCREWS AND NUTS

TABLE I TABLE OF DIMENSIONS OF SCREWS

D	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	7/8	1
P	28	24	24	20	20	18	18	16	16	14	14
A	9/32	21/64	13/32	29/64	9/16	39/64	23/32	49/64	13/16	29/32	1
A	7/32	17/64	21/64	3/8	7/16	31/64	35/64	19/32	21/32	49/64	7/8
B	3/8	1/2	9/16	11/16	3/4	7/8	15/16	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{7}{16}$
C	3/32	3/32	1/8	1/8	3/16	3/16	1/4	1/4	1/4	1/4	1/4
E	5/64	5/64	1/8	1/8	1/8	5/32	5/32	5/32	5/32	5/32	5/32
H	3/16	15/64	9/32	21/64	3/8	27/64	15/32	33/64	9/16	21/32	3/4
I	3/32	7/64	1/8	1/8	1/8	1/8	1/8	1/8	1/8	1/8	1/8
K	1/16	1/16	3/32	3/32	3/32	3/32	3/32	3/32	3/32	3/32	3/32
d	1/16	1/16	3/32	3/32	3/32	1/8	1/8	1/8	1/8	1/8	1/8

All dimensions in inches. All heads and nuts to be semi-finish. Material for all screws and nuts—steel, tensile strength, not less than 100,000 lb. per square inch, and elastic limit not less than 60 000 lb. per square inch.

TABLE 2. FORM OF THREAD, UNITED STATES STANDARD

DIAMETER	PITCH	LENGTH OF THREADED PORTION	DIAMETER OF HEAD ACROSS FLATS	THICKNESS OF HEAD	DIAMETER OF FACING UNDER HEAD	DEPTH OF FACING UNDER HEAD	WIDTH OF SLOT IN HEAD	DEPTH OF SLOT IN HEAD	DIAMETER OF COTTER PIN HOLE
$\frac{1}{4}$	28	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{3}{8}$	$\frac{1}{64}$	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{5}{64}$
$\frac{5}{16}$	24	$\frac{15}{32}$	$\frac{1}{2}$	$\frac{15}{64}$	$\frac{1}{2}$	$\frac{1}{64}$	$\frac{1}{16}$	$\frac{7}{64}$	$\frac{5}{64}$
$\frac{3}{8}$	24	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{9}{32}$	$\frac{9}{16}$	$\frac{1}{64}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{1}{8}$
$\frac{7}{16}$	20	$\frac{21}{32}$	$\frac{11}{16}$	$\frac{21}{64}$	$\frac{11}{16}$	$\frac{1}{64}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{1}{8}$
$\frac{1}{2}$	20	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{3}{4}$	$\frac{1}{64}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{1}{8}$
$\frac{9}{16}$	18	$\frac{27}{32}$	$\frac{7}{8}$	$\frac{27}{64}$	$\frac{7}{8}$	$\frac{1}{64}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{32}$
$\frac{5}{8}$	18	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{15}{32}$	$\frac{15}{16}$	$\frac{1}{64}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{32}$
$\frac{11}{16}$	16	$1\frac{1}{32}$	1	$\frac{33}{64}$	1	$\frac{1}{64}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{32}$
$\frac{3}{4}$	16	$1\frac{1}{8}$	$1\frac{1}{8}$	$\frac{9}{16}$	$1\frac{1}{8}$	$\frac{1}{64}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{32}$
$\frac{7}{8}$	14	$1\frac{5}{16}$	$1\frac{1}{4}$	$\frac{21}{32}$	$1\frac{1}{4}$	$\frac{1}{64}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{32}$
1	14	$1\frac{1}{2}$	$1\frac{7}{16}$	$\frac{3}{4}$	$1\frac{7}{16}$	$\frac{1}{64}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{32}$

No. 1143

COLLAPSING PRESSURES OF LAP-WELDED STEEL TUBES

THE EFFECTS OF THE DISTORTION DUE TO SUCCESSIVE RETESTS ON THE COLLAPSING PRESSURES OF 10-INCH LAP-WELDED STEEL TUBES.[1]

BY PROF. REID T. STEWART, PITTSBURG, PA.
Member of the Society

The paper to which this is a supplement was presented at the Chattanooga meeting and gives the principal results of a very complete research on the collapsing pressures of commercial lap-welded steel tubes. The tubes referred to in that paper were in normal condition as to commercial roundness; whereas this supplement deals with tubes that are commercially abnormally out-of-round.

2 While testing the 10-inch tubes No. 445 to 454, inclusive, the conditions were found to be such that with the apparatus in use, it was practicable to make a series of retests on each of these tubes. This was rendered possible because of the small extent of the recoil of the test apparatus which for these tubes caused but slight permanent distortion after each successive failure. Indeed this permanent distortion in some cases was so slight after the first failure as to be scarcely noticeable to the eye. See Fig. 62, which is a reproduction of a photograph taken after the removal of No. 450 to 454 from the test apparatus, after the completion of the first test.

SCHEME OF SUCCESSIVE RETESTS

3 The scheme of these retests was as follows:

a Autographic calipering diagrams of the tubes, before insertion in the Hydraulic Test Cylinder, were made in order to determine the precise initial out-of-roundness of the

[1] Supplement to a paper by the author on "The Collapsing Pressures of Lap-Welded Steel Tubes." See Transactions of The American Society of Mechanical Engineers, Volume 27, pp. 730-822.

Presented at the Indianapolis, Ind., Meeting (May, 1907) of The American Society of Mechanical Engineers, and forming part of Volume 29 of the Transactions.

tube at each foot along its length. (See Volume 27, pp. 746-752, of the Transactions of this Society.)

b The tube was then inserted in the test cylinder and a fluid collapsing pressure was gradually applied as in the previous experiments, care being taken to stop the hydraulic pressure pump instantly on the gages showing that failure had occurred.

c The tube after removal from the test cylinder was carefully calipered for the purpose of determining the permanent distortion it had suffered, after which it was reinserted and the test proceeded with as before. In this way for tubes of comparatively thin walls, 10 inches outside diameter and 20 feet long, a series of decreasing collapsing pressures was had corresponding to a series of increasing departures from roundness.

TABLE OF SUCCESSIVE RETESTS ON 10-INCH TUBES

4 Table 63, showing the successive retests, is an abstract from the Log of Collapsing Tests, and shows the effects of retesting No. 445

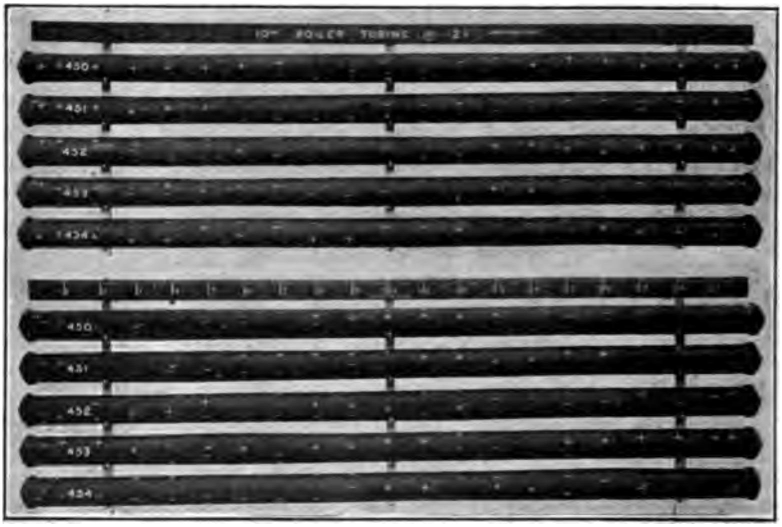


Fig. 62 From Photograph of Tests No. 450-454, Showing the Slight Permanent Distortion Resulting from the First Failure of the Tubes. Place of Failure Indicated by Arrow

to 454, inclusive, according to the scheme above indicated. The complete data relating to the first test of each of these experimental

TABLE 63

SUCCESSIVE RETESTS ON NATIONAL TUBE COMPANY'S LAP-WELDED BESSEMER-STEEL TUBES, 10 INCHES OUTSIDE DIAMETER, AND 20 FEET LONG

By R. T. Stewart, 1905

1	2	3	4	5	6	7	8
Test No.	Retest No.	Collapsing pressure, pounds per square inch	After collapse		Max. O.D. + Min. O.D. at place of collapse		Remarks
			Max. O.D. inches	Min. O.D. inches	Before testing	After testing	
445	—	210	11.18	8.67	1.024	1.289	Nominal o. d. = 10 in.
	1	87	11.37	8.42	1.289	1.350	Actual average outside
	2	82	11.44	8.34	1.350	1.372	diam. = 10.037 in.
	3	77	11.66	7.95	1.372	1.467	Average thickness of wall
	4	70	11.68	7.89	1.467	1.480	= 0.167 in.
	5	70	12.18	6.72	1.480	1.813	Plain end weight per ft. =
	6	60	12.83	5.36	1.813	2.394	17.58 lbs.
							Length of tube = 20 ft.
446	—	225	10.44	9.60	1.021	1.088	Nominal o. d. = 10 in.
	1	150	10.62	9.30	1.088	1.131	Actual average outside
	2	135	10.76	9.12	1.131	1.180	diam. = 10.031 in.
	3	115	10.83	9.00	1.180	1.203	Average thickness of wall
	4	110	10.89	8.92	1.203	1.221	= 0.167 in.
	5	105	10.96	8.80	1.221	1.245	Plain end weight per ft. =
	6	100	11.03	8.67	1.245	1.272	17.59 lbs.
	7	95	11.10	8.48	1.272	1.309	Length of tube = 20 ft
	8	90	11.17	8.36	1.309	1.336	
	9	85	11.24	8.20	1.336	1.371	
	10	80	11.37	7.82	1.371	1.454	
	11	75	11.52	7.50	1.454	1.536	
447	—	240	10.58	9.50	1.020	1.114	Nominal o. d. = 10 in.
	1	150	10.71	9.30	1.114	1.152	Actual average outside
	2	135	10.96	8.94	1.152	1.226	diam. = 10.045 in.
	3	115	11.16	8.70	1.226	1.283	Average thickness of wa
	4	100	11.50	8.06	1.283	1.427	= 0.166 in.
	5	80	12.00	7.04	1.427	1.705	Plain end weight per ft. =
							17.50 lbs.
							Length of tube = 20 ft.
448	—	240	10.52	9.51	1.025	1.106	Nominal o. d. = 10 in.
	1	175	11.08	8.86	1.106	1.251	Actual average outside
	2	115	11.18	8.74	1.251	1.279	diam. = 10.035 in.
	3	110	11.25	8.63	1.279	1.304	Average thickness of wall
	4	105	11.33	8.55	1.304	1.325	= 0.170 in.
							Plain end weight per ft. =
							17.94 lbs.
							Length of tube = 20 ft.
449	—	210	10.60	9.48	1.023	1.118	Nominal o. d. = 10 in.
	1	135	10.70	9.31	1.118	1.149	Actual average outside
	2	120	10.82	9.11	1.149	1.188	diam. = 10.055 in.
	3	110	10.95	8.90	1.188	1.230	

TABLE 63—CONTINUED

Successive Retests on National Tube Company's Lap-welded Bessemer-steel Tubes, 10 Inches Outside Diameter, and 20 Feet Long

1	2	3	4	5	6	7	8
Test No.	Retest No.	Collapsing pressure, pounds per square inch	After collapse: Max. o. d. inches	After collapse: Min. o. d. inches	Max. o.d. ÷ min o. d. at place of collapse: Before testing	Max. o.d. ÷ min o. d. at place of collapse: After testing	Remarks
449	4	100	11.04	8.71	1.230	1.268	Average thickness of wall
Con-	5	90	11.16	8.57	1.268	1.302	= 0.157 in.
tinued	6	80	11.22	8.37	1.302	1.341	Plain end weight per ft.
	7	75	11.31	8.18	1.341	1.383	= 16.55 lbs.
	8	70	11.37	8.08	1.383	1.407	Length of tube = 20 ft.
	9	65	11.88	6.70	1.407	1.773	
450	—	425	10.71	9.32	1.029	1.149	Nominal o. d. = 10 in.
	1	230	10.92	9.05	1.149	1.207	Act. ave. o. d. = 10.027 in.
	2	195	11.07	8.83	1.207	1.254	Average thickness of wall
	3	175	11.34	8.48	1.254	1.337	= 0.206 in.
	4	145	11.57	7.81	1.337	1.482	Plain end weight per ft. = 21.57 lbs.
							Length of tube = 20 ft.
451	—	390	10.79	9.28	1.020	1.163	Nominal o. d. = 10 in.
	1	205	10.97	9.02	1.163	1.216	Act. ave. o. d. = 10.029 in.
	2	175	11.17	8.78	1.216	1.272	Average thickness of wall
	3	150	11.52	8.41	1.272	1.370	= 0.194 in.
							Plain end weight per ft. = 20.35 lbs.
							Length of tube = 20 ft.
452	—	305	10.62	9.33	1.025	1.138	Nominal o. d. = 10 in.
	1	160	10.73	9.06	1.138	1.184	Act. ave. o. d. = 10.005 in.
	2	137	10.95	8.71	1.184	1.257	Average thickness of wall
	3	112	11.27	7.88	1.257	1.430	= 0.185 in.
	4	90	12.05	6.13	1.430	1.966	Plain end weight per ft. = 19.43 lbs.
							Length of tube = 20 ft.
453	—	395	10.75	9.25	1.024	1.162	Nominal o. d. = 10 in.
	1	200	10.95	9.03	1.162	1.213	Act. ave. o. d. = 10.033 in.
	2	170	11.15	8.77	1.213	1.271	Average thickness of wall
	3	150	11.36	8.25	1.271	1.377	= 0.190 in.
							Plain end weight per ft. = 19.94 lbs.
							Length of tube = 20 ft.
454	—	400	10.85	9.24	1.019	1.174	Nominal o. d. = 10 in.
	1	185	11.12	8.90	1.174	1.249	Actual average outside
	2	150	11.37	8.58	1.249	1.325	diam. = 10.037 in.
	3	125	11.75	7.94	1.325	1.480	Average thickness of wall = 0.195 in.
							Plain end weight per ft. = 20.54 lbs.
							Length of tube = 20 ft.

tubes will be found in the folders of Series 2, p. 787, Fig. 39, Volume 27, of the Transactions of this Society.

5 For convenience, however, the *principal results of the first tests* are given in the accompanying table of successive retests. For example, in this table opposite test No. 446 we read for the first test, in column three, 225 pounds per square inch as the fluid collapsing pressure; in columns four and five, 10.44 and 9.60 inches as the maximum and minimum outside diameters of the tube, at place of greatest distortion, after collapse; in column six, 1.021 as the maximum divided by the minimum outside diameter at the place of collapse before the tube was placed in the hydraulic test cylinder, and, in column seven, 1.088 as this same ratio after failure of the tube had occurred. In the "remarks" column will be found the nominal and actual average outside diameters of tube, the average thickness of wall, the plain end weight, and the length of tube between transverse joints tending to hold it to a circular form. For more complete data relating to these tubes upon the first test look for the test numbers in the above reference, folder Fig. 39.

6 The *principal results of the successive retests* are found opposite the different retest numbers given in column 2. Thus for test number 446 the first, second, and third retests show respectively collapsing pressures of 150, 135, and 115 pounds as compared with 225 pounds for the tube on its first test, or when free from distortion due to overstressing; that is to say, when the tube is normally round. Similarly the other columns of this table give for the different successive retests the values as indicated by their respective headings; thus in column 6 we find 1.09, 1.13, and 1.18 to be the maximum divided by minimum outside diameters at the place of greatest distortion before testing, for the first, second, and third retests, respectively, as compared with 1.02 for the same tube when in its original normal condition.

7 The inference is then, for this particular case, namely, experimental tube No. 446, that these collapsing pressures of 225, 150, 135, and 115 pounds correspond to differences of outside diameters at place of failure, of 2, 9, 13, and 18 per cent respectively.

CHART OF RESULTS OF SUCCESSIVE RETESTS

8 Fig. 64 shows the collapsing pressures due to the distortions caused by successive retests on the National Tube Company's lap-welded Bessemer-steel tubes, 10 inches outside diameter and 20 feet long, the retests being made on tubes of two thicknesses of wall, one averaging 0.165 and the other 0.196 inch.

9 It will be observed that the values of columns 3 and 6 of Table

63 are plotted on this chart to a vertical scale representing collapsing pressure in pounds per square inch, and to a horizontal scale representing the out-of-roundness of the tube before insertion in the test cylinder, this out-of-roundness being represented by the quotient resulting from dividing the maximum by the minimum outside diameter at place of greatest distortion.

10 In this chart the crosses represent plotted values of individual experiments, while combined crosses and circles represent the different group averages of these experiments.

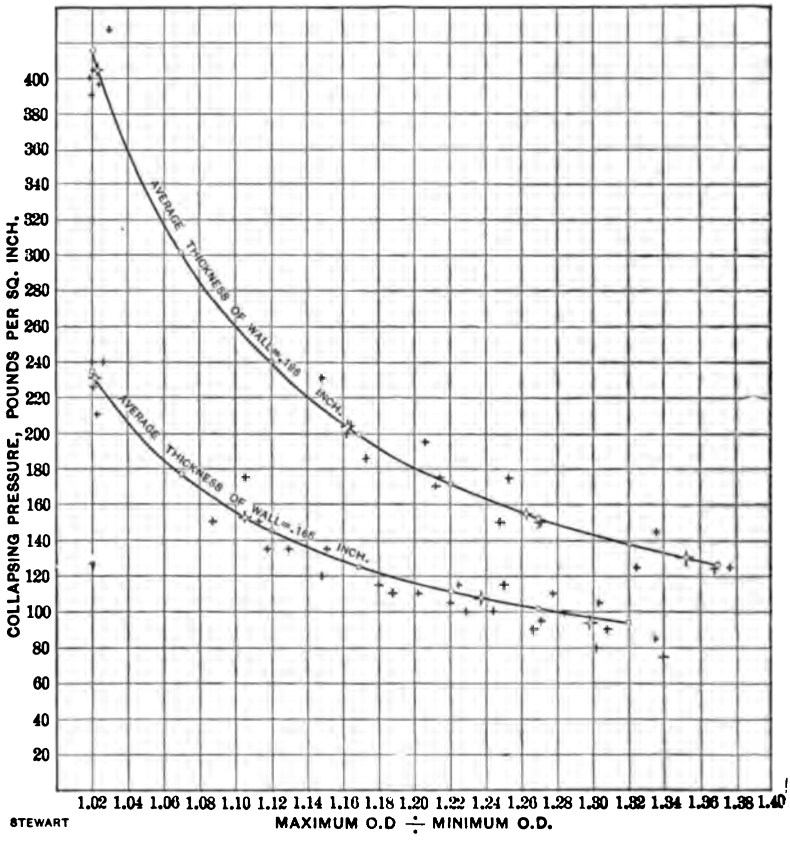


FIG. 64 CHART SHOWING COLLAPSING PRESSURES DUE TO DISTORTION CAUSED BY SUCCESSIVE RETESTS ON LAP-WELDED BESSEMER-STEEL TUBES, 10 INCHES OUTSIDE DIAMETER AND 20 FEET LONG

FORMULA FOR SUCCESSIVE RETESTS ON 10-INCH TUBES

11 An empirical formula has been derived to represent the series of values plotted, namely, those corresponding to tests No. 446–454,

inclusive, omitting No. 452 as differing too much in thickness from the average of the group to which it belonged. Values calculated by means of this formula are plotted on the chart by means of the circles through which are drawn the curves that show how the collapsing pressure is related to out-of-roundness of tube caused by overstressing for thicknesses of 0.165 and 0.196 inch, for 10-inch tubes that are 20 feet long between end connections tending to hold them to a circular form.

12 This formula represents exceedingly well the results of the experiments on the lap-welded Bessemer-steel tubes that were subjected to successive retests, as is evident from the curves representing the formula passing substantially through the group averages. The formula is:

$$P_2 = 0.0926 \frac{P_1 - 47.55}{(M - 0.874)^{1.25}} + 47.55 \qquad [J]$$

Where P_1 = collapsing pressure of normally round tube.
P_2 = that of the distorted tube, both being expressed in pounds per square inch.
M = maximum divided by minimum outside diameters at place of greatest distortion.

13 This *formula is strictly applicable*, for the kind of distortion to which it applies, to lap-welded Bessemer-steel tubes for a range of thickness of wall from 0.15 to 0.20 inch for 10-inch tubes whose lengths are 20 feet between end connections tending to hold them to a circular form. The practical range of applicability is of course beyond the above narrow limits, but to just what extent is as yet, in the absence of more complete experiments, unknown.

CONCLUSIONS

A study of the chart, Fig. 64, showing the results of successive retests on two thicknesses of 10-inch lap-welded Bessemer-steel tubes, will lead to the following conclusions, namely:

a There is a definite relation existing between the collapsing pressure of a tube and its out-of-roundness, as expressed by dividing the maximum by the minimum outside diameter at place of greatest distortion. This is clearly shown by the remarkable smoothness of a curve drawn through the different group averages represented on the chart by combined circles and crosses.

b An out-of-roundness of 10 per cent, corresponding to a difference in diameter of one inch for a 10 inch tube, which is about five times that of the commercial lap-welded tube while in its normal condition as to roundness, causes a decrease in the collapsing pressure of about one-third. From this it would appear that a lap-welded steel tube when in service, if designed with an ample safety factor, of say five for ordinary conditions, could not possibly fail because of any local out-of-roundness that would be apt to pass ordinary inspection.

No. 1144

BALANCING OF PUMPING ENGINES

An Investigation as to the Proper Weight of the Plungers of a Vertical, Triple-Expansion, Crank and Flywheel Pumping Engine

By A. F. NAGLE, BUFFALO, N. Y.
Member of the Society

The above named type of engine is capable of such high thermal and mechanical efficiency that it has practically become a standard type for city use when a high duty is desirable. The calculations in this paper are made more with the view of calling attention to the possibility of producing less vibrations within the mechanism than to effect any material fuel economy, although a slight gain will be obtained by reducing the weight of the flywheels commonly used, which is possible when the plungers are properly weighted.

2 It is frequently stipulated in specifications that the steam work in the three cylinders shall be equally divided among them, but this is not possible while preserving the sizes of cylinders judged by the designing engineer to be necessary in order to produce the highest steam economy. As an illustration of the distribution of work among the three cylinders of a modern high duty engine, I have studied its steam cards taken during the duty trial, and ascertained the division of work. To carry the study a little further, I have computed the probable division of work when the load was increased 20 per cent and diminished 15 per cent. These results will be found in Table 1.

TABLE 1

Percentage of Work in Each Cylinder at Different Loads

Power of engine per cent	Number of expansions	H. p. cyl. per cent	I. p. cyl. per cent	L. p. cyl. per cent
120	24	27.40	34.00	38.60
100	30	33.00	30.00	37.00
85	38	35.80	30.00	34.20
Mean		32.07	31.33	36.60

Presented at the Indianapolis, Ind., Meeting (May 1907) of The American Society of Mechanical Engineers, and forming part of Volume 29 of the Transactions.

3 The cylinder dimensions were 32 in., 60 in., 90 in. by 5 ft.; piston rods 7½ in., plungers 37 in. The ratio of cylinders was 1 : 3.59 : 8.11.

4 If the 100 per cent of power could be taken as the more general average condition, a more even distribution of work would be obtained by making the intermediate plunger 36¼ inches, the low pressure 37¾ inches and leaving the high pressure 37 inches. Whether such refinement of proportions is justified by the circumstances must be left to the judgment of the engineer in charge.

5 I wish, however, to call more especial attention to the relation between the loads, or varying heads, and the weight of the plungers—including in this term the steam pistons and all vertically moving parts.

6 If the steam valves are so adjusted as to give equal steam work on the up and down strokes, why should not the water end be so constructed that it will give equal resistance on the up and down strokes? I purpose to give the computation by which this may be accomplished.

7 The following heads on the suction and discharge may exist:

CONDITIONS OF HEADS (CENTER OF PUMP = 0)

Discharge, maximum	+212 feet
Discharge, mean	+200 feet
Discharge, minimum	+180 feet
Suction, maximum (lift)	− 12 feet
Suction, mean (pressure)	+ 10 feet
Suction, minimum (pressure)	+ 32 feet

Five extreme conditions of combined heads may be considered:

First	Maximum discharge	212 feet	= 91.80 pounds
	Maximum suction	−12 feet	= −5.20 pounds
	Net head	224 feet	= 97.00 pounds
Second	Minimum discharge	180 feet	= 77.94 pounds
	Maximum suction	−12 feet	= −5.20 pounds
	Net head	192 feet	= 83.14 pounds
Third	Mean discharge	200 feet	= 86.60 pounds
	Mean suction	10 feet	= 4.33 pounds
	Net head	190 feet	= 82.27 pounds
Fourth	Maximum discharge	212 feet	= 91.80 pounds
	Minimum suction	32 feet	= 13.86 pounds
	Net head	180 feet	= 77.94 feet

Fifth	Minimum discharge	180 feet	= 77.94 pounds
	Minimum suction	32 feet	= 13.86 pounds
	Net head	148 feet	= 64.08 pounds

8 In the following calculations pounds pressure will be used in place of feet head—one foot head of water, for one square inch area, weighing 0.433 pounds.

9 The mean net pressures found in the five cases are, of course, the sums of the means of the up and down strokes, and to equalize the work each should be one-half of this. The five cases would then stand as follows:

TABLE 2

Case 1	Total net pressure = 97.00 pounds	Each stroke = 48.50 pounds
Case 2	Total net pressure = 83.14 pounds	Each stroke = 41.57 pounds
Case 3	Total net pressure = 82.27 pounds	Each stroke = 41.13 pounds
Case 4	Total net pressure = 77.94 pounds	Each stroke = 38.97 pounds
Case 5	Total net pressure = 64.08 pounds	Each stroke = 32.04 pounds

10 To obtain the actual work of the pump, the above pressures should be multiplied by the area of the plunger, but that may be neglected for the present.

11 To equalize the work on the pump end of the engine we have the water pressures (per square inch) and the weight of plunger (also represented by pressure per square inch) to consider. The latter being an unknown quantity we will call it x; the former, s plus or minus, as the suction water stands above or below the center of the plunger, and d the discharge pressure.

12 Then to equalize the up and down strokes, we should have $x \pm s$ for the up stroke equal $d - x$ on the down stroke, or

$$\left(2x = d \pm s \quad \text{or} \quad x = \frac{d \pm s}{2}\right)$$

13 Hence we have the rule, that to equalize the work on the up and down strokes, make the weight of the plunger as represented by the pressure per square inch, one-half of the *algebraic* sum of the suction and discharge pressures.

14 For the five cases taken we would then have the following results:

$$\text{Case 1} \qquad \frac{91.80-5.20}{2}=43.30$$

To prove the correctness of this (weight) on the up stroke there would be a resistance of

$$43.30\ (\text{weight})+5.20\ (\text{suction}) = 48.50$$

on the down stroke there would be the discharge pressure

$$91.80-43.30\ (\text{weight}) \qquad = 48.50$$

Case 2 $$\frac{77.94-5.20}{2}=36.37$$

Proof, up stroke $36.37+5.20=41.57$
down stroke $77.94-36.37=41.57$

Case 3 $$\frac{86.60+4.33}{2}=45.46$$

Proof, up stroke $45.46-4.33=41.13$
down stroke $86.60-45.46=41.13$

Case 4 $$\frac{91.80+13.86}{2}=52.83$$

Proof, up stroke $52.83-13.85=38.97$
down stroke $91.80-52.83=38.97$

Case 5 $$\frac{77.94+13.86}{2}=45.90$$

Proof, up stroke $45.90-13.86=32.04$
down stroke $77.94-45.90=32.04$

15 Grouping these figures together for better comparison we have Table 3.

TABLE 3

1	2 ½ pump load per square inch	3 Balancing pressure per square inch	4 Actual weight of plunger, pounds
Case 1	48.50	43.30	46,556
Case 2	41.57	36.37	39,105
Case 3	41.13	45.46	48,878
Case 4	38.97	52.83	56,803
Case 5	32.04	45.90	49,351
Average	40.44	44.77	48,137

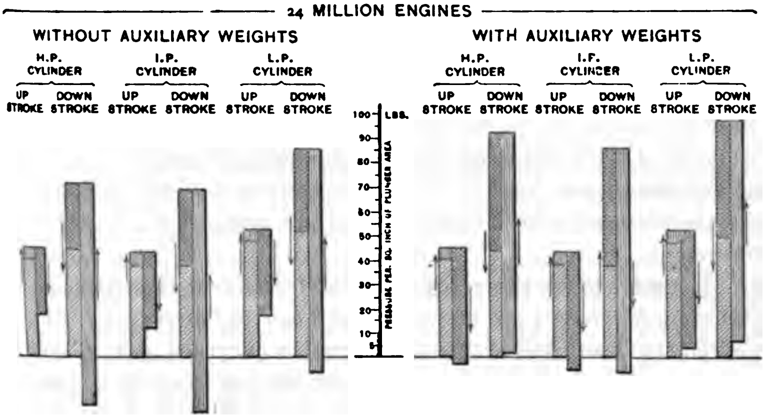
Column 4 is found by multiplying the pressure by the area of the 37 inch diameter, which is equal to 1075.20 square inches.

16 It is noticeable that while the net pump loads may be nearly the same as in cases 2 and 3, the balancing pressures may differ 25 per cent. Also, the pump loads may differ 50 per cent, as in cases 1 and 5, and yet the balancing pressures differ but 6 per cent.

17 If case 3 is the prevailing condition of water pressures, it is also very nearly the average of all possible conditions and a weight of plunger of 48,000 pounds is the best balancing weight that can be made.

18 There is no reason why flywheels in triple expansion pumping engines should be so very heavy. The turning moments during one revolution do not vary over 16 per cent; nor is absolutely uniform

rotative velocity of wheels necessary. With plungers weighted as described in this paper, I have no doubt but that many examples exist where the weight of the wheels could be safely reduced one-half. Since the above was written my attention has been called to an engine which is fully 50 per cent of its load out of balance, and yet its two flywheels are so heavy that no appreciable deviation from perfect rotative speed is observed.



WEIGHTS OF MOVING PARTS

H.P.	I.P.	L.P.
25,000 LBS.	27,700 LBS.	32,000 LBS.

WEIGHTS OF MOVING PARTS

	H.P.	I.P.	L.P.
ORIGINAL	25,000 LBS.	27,700 LBS.	32,000 LBS.
AUXILIARY	18,000 "	15,300 "	11,000 "
TOTAL	43,000 LBS.	43,000 LBS.	43,000 LBS.

SYMBOLS

STEAM WATER WEIGHT

NOTE-ARROWS INDICATE DIRECTION OF PRESSURES AND NOT THAT OF PLUNGER MOTION.

FIG. 1 DIAGRAM SHOWING UNBALANCED PRESSURES PER SQUARE INCH OF PLUNGERS WITH AND WITHOUT AUXILIARY WEIGHTS

19 The accompanying diagram, which is the result of a study of the condition of pressures existing at the Crescent Hill Station, Louisville, Ky., brings more clearly into view the advantage of properly weighted plungers. It needs but a slight acquaintance with the laws of mechanics to see how much better it is to equalize the work of the steam in the direct line of the plungers than to carry so large a proportion through the pump rods, connecting rods, cranks, and flywheels. As the natural pressure of these pumps is greatest on the down stroke, putting the long, slender, pump rods and connecting rods in compression (which is liable to produce vibrations), balancing the plungers (as is here pointed out) will also equalize the

being counterbalanced practically equal to the weight of the reciprocating parts in order that the effort on the steam piston might be equal on both up and down strokes, and it is to this latter form of balancing which Mr. Nagle's paper directly refers.

2 Diagrams by Professor Peabody showing the rotative effect, etc. on a triple expansion pumping engine were included in a paper by Dr. Thurston on the test of the Milwaukee pumping engine.[1]

3 While the approximate balancing of crank and flywheel pumps is desirable, it is much more essential in the non-rotative type of vertical direct-acting pumps where the total weight of the reciprocating parts must be balanced in order to secure equal steam diagrams on the up and down strokes.

4 Vertical crank and flywheel pumping engines are usually built with single-acting plungers, in which case it has long been customary to design the weight of plungers and reciprocating parts so as to equal half of the resistance, as described by Mr. Nagle; but to do this with great accuracy is not at all necessary, as there is no particular objection to transmitting a certain amount of power from one cylinder to another through the crank shaft and to and from the flywheels. Local conditions, moreover, sometimes prevent the accurate balancing of parts. For instance where the water pressure is very light, the weight of the reciprocating parts would be greater than necessary to balance the pressure, and consequently the machine would be overbalanced. The writer recalls two cases of very successful engines where this was the case.

5 The other extreme is where the water pressure is very heavy, which condition may be still further aggravated by heavy pressure on the suction side of the pump, as the balancing must be against the sum of the two pressures. In cases of this kind, it is not always possible to apply weight enough to the plungers, even if made of practically solid lead, and under these conditions, it is the writer's practice to make the weight of each plunger with its reciprocating parts equal to each of the other plungers and reciprocating parts, regardless of the total balancing effect.

6 It not infrequently happens that a pumping engine occasionally operates against a fire pressure about 50 per cent greater than the normal working pressures, and it is customary and is found entirely satisfactory to approximately balance against the normal pressure only, paying no attention whatever to the extreme pressures.

[1] Transactions of the Society, vol. 15.

7 While it is true that the accurate balancing of plungers enables lighter flywheels to be used, yet the abnormally heavy wheels, of which Mr. Nagle speaks, are most frequently employed for the purpose of enabling the engine to turn steadily at very slow speed; a very common condition being that the engines shall run down to one-half or one-third of their normal speed while remaining under the control of the speed governor acting through trip cut-offs, and this cannot be satisfactorily done unless the engine turns at a fairly uniform speed.

8 There is a limited class of pumping engines using practically full stroke steam valve gear (for hydraulic work, etc.), which can be operated practically without flywheels and are so built, but with the high duty type of pumping engine under consideration where the steam is cut off at one-third stroke or less, uniform rotative speed cannot be secured, nor in fact can the engines run at all at low speeds, without fairly heavy flywheels.

9 To recapitulate: Accurate balancing is essential for vertical non-rotative engines; approximate balancing is desirable for vertical rotative engines, but may vary within wide limits without harmful effect. The use of lighter flywheels is possible on engines which are to be operated at substantially full speed at all times, but it is not advisable for general practice.

10 Mr. Nagle suggests the advisability of purchasers stating the exact piston speed at which engines shall be run rather than the maximum speed, and while this would bring about the desirable feature of having all bids on the same basis, I believe it can be accomplished in a more satisfactory manner As nearly all pumping machinery is purchased by municipalities and under contracts which are naturally awarded to the lowest bidder, it is of the highest importance that the specifications confine the bids to machinery of one character and of practically the same size and value, but at the same time they should be elastic enough to permit of some slight variation.

11 To limit the speed absolutely to a definite figure, as suggested by Mr. Nagle, would compel every builder to bid on the same sizes of cylinders and perhaps require new patterns, while some manufacturer might have patterns varying slightly from the required sizes which, with an unimportant change in speed, would suit the case exactly. Every change in steam or water pressure affects the sizes of the steam cylinders or the piston speed; each set of steam cylinders being capable of exerting a certain "plunger effort" for each steam pressure.

12 As a case in point, the writer has recently used the same steam end for four different pumping engines, one each of 8 000 000, 10 000-

000, 12 000 000 and 14 000 000 gallons capacity, and all having different steam pressures, and all different water pressures; this arrangement being possible by slight changes in the speed and very considerable changes in plunger diameters.

13 Specifications issued by the purchaser should be explicit and the engineer should decide in advance what type of machinery is best suited for his purpose, and the bids should be confined strictly to it. The maximum piston speed should be limited to a figure which may be considered well within the range of good practice, but in all cases, the specifications should prescribe also the *minimum stroke* permitted, as otherwise the conservative builder will figure on a long-stroke-slow-revolution machine, while another builder, in his anxiety to make a low bid, will figure on an inferior machine of shorter stroke and higher revolutions.

14 The specification should state the matter in about this form: "The engine shall deliver 20 000 000 gallons in 24 hours when operated at a plunger speed not exceeding 225 ft. per minute. The stroke of the steam pistons and plungers shall not be less than 60 in., and the engine must be capable of safely operating at a speed 10 per cent above the normal without appreciable loss in economy."

15 A great mistake has been made in the past in considering *piston speed* as the important item, whereas in pumping engines it is important only in connection with the *stroke* of the engine as determining the *number of revolutions* per minute.

MR. E. H. FOSTER One point which has not been mentioned is the effect on the balancing caused by submergence of the plunger. A plunger which has a 5 ft. stroke will be affected by submergence to the extent of 2½ per cent when the pump is delivering against a 200 ft. head, and 10 per cent on a 50 ft. head. That is to say, there will be this difference in power required to move the plunger at the top or at the bottom of the stroke, due to submergence. This should properly be taken into consideration in settling upon the balancing weight.

2 The point brought out of a pump working against a variable head is very important, as it is impossible to balance an engine accurately by dead weight when such conditions prevail.

3 After all are not the disadvantages of an unbalanced engine more practical than theoretical? Engines which were not balanced have shown the effect by a lifting of the shaft causing pounding, and I consider it somewhat a disadvantage of the type of engine under discussion that balancing is necessary. It adds, for instance in the

case which Mr. Nagle cites, a load of about 10 or 15 tons which the engine will have to carry at all times, and which would be avoided in the case of an engine not required to be balanced.

4 In regard to drawing specifications for certain types of pumping engines, I think that is generally a mistake. I have had experience on both sides of this question, acting at different times for both the designer and for the purchaser of pumping engines, and I have never found the purchaser to have suffered in any way by issuing open specifications provided he has safeguarded his interests by the usual right to reject bids which it does not seem advisable to accept. Much depends upon the competence of the purchaser's engineer, and when he is not experienced in that particular line I think it is quite in order to call in an expert after the bids are opened. A designer should, in my opinion, always be given a chance to improve upon previous work when a pumping engine is to be purchased.

5 I do not know of any class of machinery more subject to prejudice as to types, than are pumping engines, nor one more subject to fads. At one time one style is very much in vogue and then another. I believe it is very desirable to leave the bars down so far as possible, so that the designers may have all the opportunities offered to show what they can do.

THE AUTHOR Replying to Mr. Foster, on the effect of submergence of the plunger, is that not covered by the expression "lift or pressure on the suction side" and shown in the formula by a minus or plus sign? The statement by Mr. Foster that the balancing weight adds, in the case cited, 10 or 15 tons needless weight, thus adding to its friction, is erroneous, for it only equalizes the work of frictions between the up and down strokes. The friction losses are increased by a needlessly heavy flywheel, as pointed out in the paper, but not by the balancing weights.

2 Mr. Reynolds reviews the paper so intelligently and broadly that I can only say that when separating the commercial, or manufacturing interests from the strictly engineering view, I can add nothing. The special cases in point to which he calls attention could be met as pointed out in the paper, with such additional changes as the circumstances called for.

No. 1145

THE ECONOMY OF THE LONG KILN

TESTS ON 7 FT. BY 60 FT. AND 8 FT. BY 110 FT. ROTARY KILNS BURNING NATURAL GAS

BY E. C. SOPER, SOUTH PITTSBURG, TENN.
Member of the Society

One of the most important steps in the manufacture of Portland cement is the burning or calcination of the raw material into clinker. Briefly described, the manufacture of Portland cement consists of three steps.

a Mixing and grinding the raw material.
b Burning.
c Grinding the resultant clinker.

2 Because of the high cost of fuel incident to its production, the burning is of vital importance. It is not our province to go into the history of the industry nor of the burning process in particular, and we will only say that the old vertical kiln gave way to the rotary kiln, because of the greater economy in labor, and up to the last two or three years the standard size of the rotary in use was about 6 ft. by 60 ft.; today the preferred size is from 7 ft. to 8 ft. in diameter and varies from 60 ft. to 150 ft. in length, with the 100 ft. length kiln favored by the majority of the progressive manufacturers.

3 The kiln question, however, is still in a transitory stage, because of the keen competition and rivalry among the 95 different operating companies, and reliable data are not easily available. Just what sizes will be adopted as standard, if any, would be difficult to prognosticate at the present time. There are some of the manufacturers actually claiming from 400 to 500 barrels per day per 60 foot kiln, and some of the mills in the Lehigh district with 135 foot kilns have made as high as 750 barrels per day, but as to fuel economy, the information is not given out. Whatever fuel is used in the calcining of the raw material, approximately the same number of heat units must necessarily be

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required per barrel of clinker burned. The rotary kiln, even in its most improved installation, is not an economical proposition in point of fuel, as its highest efficiency is less than 50 per cent. In other words, the heat actually consumed per barrel is generally more than double that actually required for the calcining and chemical processes involved.

4 In an ordinary 60 foot kiln installation, it generally requires 200 pounds of coal to burn one barrel of cement. Slack coal is generally used with the ash percentage varying from 5 to 15 per cent. Some manufacturers we believe have reduced this consumption to 85 pounds but the majority of the averages is about 120 pounds per barrel. This does not include the coal used in drying the raw materials and drying the coal itself and the coal required for power; these items will increase this amount to, say 150 pounds of coal per barrel, and

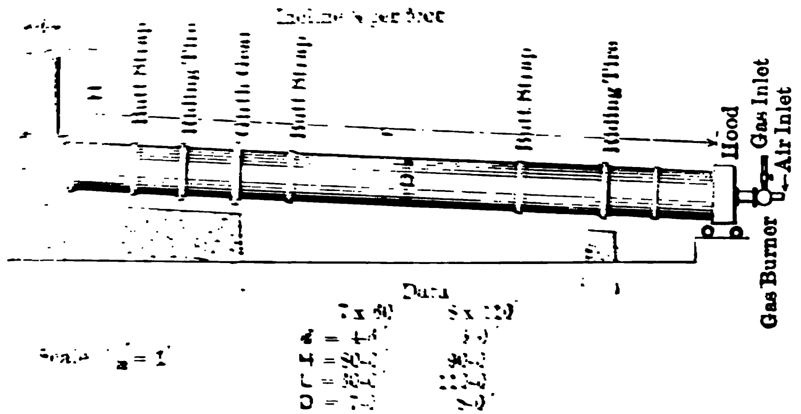


FIG. 1 SHOWING INSTALLATIONS OF KILNS

with the average price of coal at $2, gives an actual cost of fuel per barrel of 15 cents. The average cost of manufacturing Portland cement in a modern up to date plant in the Lehigh district is 70 cents per barrel, thus the fuel cost is 20 per cent, and this figure is a conservative average. According to the heat balance, the fuel consumption should be but one half of what is actually required in the best practice of today.

5 The burning of Portland cement by natural gas is an entirely different proposition, in point of installation, from the usual pulverized coal system. In the drawing above is given a typical installment. Gas is fed into a Kirkwood burner, of which there are many sizes. The burner is essentially a double cylinder with gas connection with the outer shell; a series of small perforated pipes perpendicular

to the axis of the cylinder and equal in length to the diameter of the inner cylinder allows the gas to flow into these pipes and out through the perforations into the inner cylinder, from whence it is blown by air furnished by a blower into the kilns. Fig. 2 shows a typical "Kirkwood burner," patented by Tate, Jones & Co., Inc. The gas is fed into the burner or mixer under an average pressure of about 2 pounds and the air pressure varies from 1 to 6 ounces in different plants.

6 The actual heat requirements in the burning process are as follows:

a Evaporations of moisture in dry mix.
b The driving off of the carbonates and sulphates.
c The heating of the material to clinkering temperature.

The losses occur as follows:

a Heating and evaporation of excess moisture.
b Heat contained in discharge of clinker.
c Heat radiated by kiln.
d Heat carried off by waste gases.

FIG. 2 THE GAS BURNER USED

7 The latter process is one of the greatest sources of loss in the older installations and was the chief cause of the bringing out of the "long kiln." In a 60 foot kiln, operating dry process, the stack temperature varies from 1000 to 1500 deg. fahr., in some cases they have been measured up to as high as 2000 deg. fahr. In the use of the long kiln these temperatures may be reduced in amount to 400 to 700 deg. fahr. and the fuel consumption correspondingly decreased. Prof. Carpenter's method of utilizing the waste heat from the ordinary 60 ft. kiln under boilers is probably a more ideal method than lengthening the kiln, but for some reason, probably mechanical, it has been adopted in but one or two plants, and we understand that it is not a practical installation.

8 When natural gas was first utilized for burning in rotary kilns the number of cubic feet per barrel much exceeded that required at the present time, and even now when a kiln is first put into operation and until the lining is thoroughly "coated" the consumption per barrel is nearly double what it is after the kiln has been in operation for sometime.

9 The results of the tests given below are not from one day's operation but from several months' run. The heat distribution is given merely to show what work is still necessary before the heat requirements of the rotary kilns are reduced to as low a figure as is practical.

10 There is one big difference in a gas flame and the ordinary pulverized coal flame. The coal flame flares in a gradually increasing "cone" while the gas flame is similar to a "mushroom" and the heat zone is much nearer the discharge end of the kiln than in the cases of the coal burning system.

11 There are approximately 600 pounds of raw material required to produce one barrel of Portland cement clinker. A cubic foot of natural gas contains approximately 1000 British heat units.

12 The kilns below are operating on practically the same raw materials, under the same process and supervision. The proportions are, roughly, 75 per cent lime stone and 25 per cent shale:

TESTS

Size kilns	7 ft. by 60 ft. kiln	8 ft. by 110 ft. kiln
Date	Oct. 1, 1906	Nov. 1, 1906
Capacity of kiln, 24 hours	200 barrels	450 barrels
Cu.ft. gas actually required per barrel	2750 deg. fahr.	2000
Temperatures observed		
Stack gases	1300 deg. fahr.	450 deg. fahr.
2 feet inside nose ring	2400 deg. fahr.	
Temperatures discharged clinker	1380 deg. fahr.	1380 deg. fahr
Atmosphere	70 deg. fahr.	70 deg. fahr
Air pressure at burner in ounces per square inch	1.15	5
Diameter blow pipe	10 in.	16 in.
Size burner	12 in.	16 in.
Average speed of kiln	1 revolution in 1½ minutes.	1 revolution in 4 minutes.
Average horse power	12	20
Time required to burn 1 barrel	7.2 min.	3.2 min.
No. square feet surface in shell	1381	2765
Hood	100	172
No. lbs. dry raw material per barrel	610	610
Percentage water per barrel	33	33
No. lb. clinker per barrel produced	384	384

Analyses

Natural gas

CH_4	97.63 per cent
C_2H_4	0.22 per cent
CO_2	0.22 per cent
CO	1.33 per cent
N	0.60 per cent

Limestone	Shale	Raw mix	Clinker	Limestone	Shale	Raw mix	Clinker
SiO_2		14.4	22.1	2.5	62.7	14.9	22.3
Fe_2O_3		2.3	3.6	2.2	26.0	7.6	10.7
Al_2O		4.9	7.9				
CaO		41.00	63.0	52.2	2.5	41.2	62.5
MgO		1.64	2.63	0.8	2.4	1.8	2.1
Loss		35.30		42.1	6.2	35.0	1.4

Specific heats

Air	0.2375
Waste gases	0.23
Clinker	0.2
CO_2, SO_2	0.24
Raw mix	0.2
Steam	0.48

Heats of combination

CaO	954.0 B. t. u.
MgO	1488.6

Heats of decomposition

SO_3	1890 B. t. u.
$CaCO_3$	765

Number B. t. u. per cubic foot natural gas calculated from analysis 1088 1088

Number cubic feet air required to burn 1 cubic foot gas calculated from analysis—theoretical 9.39 9.39

DISTRIBUTION OF HEAT IN KILN PER BARREL CLINKER BURNED

		Per cent		Per cent
1 Evaporating and heating of 300 pounds water from temperature entering kiln to temperature stack; gases in B. t. u.	489,072	15.1	366,672	15.0
2 Heating 610 pounds dry mix from 70 deg. to 1000 deg.	113,460	3.5	113,460	4.6
3 Heating 384 pounds clinker from 1000 deg. to 2600 deg.	147,256	4.5	147,256	6.0
4 Heat radiated by 384 pounds clinker discharged at 1380 deg. and cooling to 70 deg.	120,729	3.7	120,729	4.9
5 Heat radiated by kiln shell and hood (calculated)	46,580	0.14	31,455	0.12

		Per cent		Per cent
6 Carried off by waste gases	777,325	24.0	202,000	8.3
7 Heat required to decompose $CaCo_3$	344,403	10.6	346,086	14.2
4 From below	15,504	0.06		
Total heat accounted for in kiln per barrel	2,054,529		1,327,258	
Unaccounted for, probably radiation and escaping in flames, shell, and hood	1,186,987	36.63	1,115,318	45.0
Total B. t. u. actually supplied	3,241,516		2,442,576	

HEAT DELIVERED TO KILN PER BARREL CLINKER BURNED

1 Contained in air entering through blow pipes in B.t.u.	1710	2,442
2 Contained in entering gas.	2000	2,012
3 Chemical action; liberated by combination of CaO	230,772	228,960
MgO	15,034	4570
4 Liberated by CO_2 and SO_2 cooling from 1000 deg. to stack temperature.	– 15,504	28,182
5 Produced by combustion of gas.	3,192,000	2,176,400
Total heat in B. t. u. received by kilns.	3,241,516	2,442,576

13 It will be noted in the above that in the long kiln a 5 ounce pressure of air was maintained. The long kiln is a more recent installation and the question of air is one which has not been given the attention it deserves by the cement engineers. In several instances where the pressure and volume have been increased in the same kiln the output has been increased from 10 to 20 per cent. The maximum output of the long kiln is 600 barrels per day, but the figure given is maintained throughout the month, including shut downs, and is therefore the one to be considered.

14 It will be noted that the stack temperature on the 60 foot kiln is about 1300 degrees, and this amounts to a loss of 24 per cent of the fuel supply to the kiln. It also means another loss through the heating of carbonates and sulphates, which are liberated at about 1000 deg. fahr. and which must be heated in the case of the 60 foot kiln and cooled in the 110 foot kiln to the temperature of the stack gases. Another means of utilizing the air which has been heated by the discharged clinker and blowing same into the kiln has saved, in some instances, as high as 10 per cent of the fuel. In other words, the fuel consumption has been decreased 10 per cent.

15 It is a question now whether or not the ideal length of the kiln should be between 100 feet and 125 feet. We have noted a kiln of the latter length and 7 feet 6 inches diameter operating under precisely the same conditions as the two above, and whose monthly average output barely equaled that of the 110 foot kiln. Of course the original cost of the latter kiln is double that of the 60 foot kiln but the labor per barrel in the burning department is one-half what it is with the 60 foot kiln, and while the horse power is proportionally more in the case of the long kiln, the increased fuel economy of 25 to 35 per cent will more than compensate for the interest on the increased cost of the installation and the increased horse power.

DISCUSSION

PROF. WILLIAM D. ENNIS Increasing the length of cement kilns, like increasing the heating surface of a boiler, gives more room for heat transfer, and consequently for a given amount of initial heat reduces the proportion of loss to the stack. With any fuel the kiln should be of sufficient length to avoid such exit temperature of gases as quoted in the first test. Much depends on the condition of the material as fed to the kiln. If this is run wet, the kiln length, fuel consumption and other relations will differ from those usual with dry material. A 110 ft. kiln is necessarily better for economy of fuel than a 60 ft. kiln, just as some of the highly efficient boilers designed by members of this Society with heating-to-grate ratios of 75 to 1 are necessarily better, on soft coal, than boilers having the ratio 50 to 1.

2 Reference is made to the customary use of pulverized coal, which is probably the standard kiln fuel in cement works where natural gas is not available. Only those coals which are high in volatile matter (upward of 30 per cent) can be used, and high percentages of moisture, which always exist in slack coals during the winter months, are difficult to handle. Pulverized coal is comparable to gunpowder in the danger element which it introduces in manufacturing plants. The operation of grinding is ordinarily disagreeable, wasteful of power and hard on the crusher, and the cost of pulverizing varies from 25 to 50 cents per ton. But with all its disadvantages, pulverized coal necessarily displaces oil, which costs about twice as much, per heat unit, in the Lehigh district. When pulverized, the coal can be burned with as little labor, and with as readily attainable sustained high efficiency, as oil.

3 There are many furnace applications, where oil is now commonly used, in which pulverized coal would be equally effective and convenient, and would cost about one-half as much; as in drop forge work, rolling mill furnaces, annealing furnaces, etc. The difficulties are rather in the preparation and handling of the coal than at the furnace, where its use is fully as simple as oil.

4 The cost of a complete pulverizing and handling equipment varies all the way from $100 to $600 per ton of daily capacity, depending upon the grade of plant, the degree of concentration of the furnaces, and other factors. Figuring this in terms of boiler horse power, the cost would be from $6 to $36 per horse power, which would be a serious item in any proposed application to steam production.

5 For cement kilns, and heating work, to replace oil, which has been increasing in price and is an expensive fuel, pulverized coal seems to promise the highest fuel economy wherever gas is not available.

MR. E. A. W. JEFFERIES The showing which Mr. Soper makes on the difference in economy between the 60 ft. and 110 ft. kiln is very remarkable.

2 An important element in determining the proper length of a rotary kiln is the question of moisture—whether or not the process is a wet or a dry one. If wet, that is having moisture over 50 per cent, should not the length of the kiln be greater to give equally good results, since it takes time and contact to get rid of the water before gas can be driven off?

3 The utilization of waste gases from rotary kilns to raise steam when the dry process is used, has been successfully carried out by Mr. John G. Jones, President of the New York Lime Company, Natural Bridge, N. Y., in an installation for burning lime. His equipment gives him as high as 7 lb. of burned lime per pound of coal under favorable conditions, and he has heat enough left to raise a large portion of the steam required about his mill. The kilns are fired with producer gas.

4 There are many installations of rotary kilns now in operation for burning lime with producer gas and the question which Mr. Soper discusses is as important in this connection as in the case of Portland cement. It would be interesting if data comparing the economy effected by lengthening the kiln in both the wet and dry processes, could be obtained. The case which Mr. Soper cites, namely 33 per cent moisture, seems to lie between the two.

PROF. R. C. CARPENTER The paper by Mr. Soper respecting the economy of the long kiln in the manufacture of Portland cement is likely to be misleading for the reason that it refers only to conditions which are extremely unusual.

2 Most Portland cement materials are thoroughly dry at the time they are fed into the kiln, consequently the kiln has to evaporate very little water. In the manufacture of cement from marl and clay, materials which were at one time extensively used in Michigan, it was the practice to feed very wet materials into the kiln, sometimes containing four times as much water as solids.

3 There are a few plants in this country in which the material is wet artificially before being fed to the kiln. My own impression is

that not over 1 per cent of our total cement is made by such a process, but regarding that point I should be glad to have some information from Mr. Soper.

4 From the amount of water which appears to have been evaporated in the kilns, 33 per cent, I understand that the tests to which the author refers were made with ground rock material to which moisture had been added, or in other words that the kiln was conducted by the very unusual method to which I referred above.

5 The results obtained with a 7 by 60 ft. kiln are extremely poor, and do not even approximate what is usually obtained with that kiln where dry material is fed at the upper end. The usual coal consumption in the Lehigh region of a kiln 60 ft. long working on the dry process averages about 90 lb. to the barrel of cement with an output of about 300 to 400 barrels per day. The additional cost of drying the material would depend upon the conditions, but usually does not vary greatly from 5 to 10 lb. of coal to the barrel.

6 The long kiln has been adopted to some extent in the Lehigh region and has resulted in an increase in economy of about 10 to 15 per cent and an increase in output of about 20 per cent.

7 The temperature in the stack in the test made with the short kiln is given as 1300 deg. fahr.; this is a reasonable temperature and perhaps a low temperature for a 60 ft. kiln burning dry material when being forced to a high capacity, but it is certainly unreasonable and remarkably high for materials which contain 33 per cent of water.

8 The statement that "Professor Carpenter's method of utilizing waste heat is not a practical installation" is, it seems to me, hardly a fair one from the fact that it has been in use successfully for over six years in one plant, and wherever proper precautions have been taken to separate the dust, it does not seem to have met with difficulty in any plant. This system is, however, one which is not ordinarily applicable where wet materials are fed into the kiln, as in the test described by Mr. Soper, and I should not expect a high average temperature to accompany good results under such conditions.

9 Respecting the use of the long kiln, it should be noted that Mr. Thomas A. Edison has a patent which covers such uses where the kiln has a length of 100 ft. or more, which I understand was granted on representations made by Mr. Edison that the processes which take place in a long kiln of say 100 ft. or over are different from those which take place in a shorter kiln of say 60 ft. in length. Whatever may be the advantages of the long kiln as compared with the short one for dry material, there can be no doubt whatever of the advantages of the

long kiln for drying out the surplus moisture where wet material is used.

10 I am not able to see any economic advantage in the process of manufacture from adding water merely for the purpose of boiling it out at a great fuel expense at a later stage. I do not, however, wish to antagonize the wet system, as described by Mr. Soper, since it is generally liked where installed, and has some advantages in the way of mixing and raw grinding. I will also admit that I designed a plant working with that process some years ago which has been so successful that the owners have never cared to change it to the dry process. The plant employs kilns 6 ft. by 60 ft. in length; it has an output per kiln averaging about 200 barrels per day, and consumes about 140 lb. of coal per barrel. In this plant there are no devices for utilizing the waste heat from the kilns, which, however, rarely have a temperature above 800 deg. fahr.

MR. BYRON E. ELDRED The data presented by the author are interesting but it is regrettable that the record is of comparative tests obtained with natural gas fuel rather than with pulverized coal, which is more commonly used. The burning of coal in suspension in the rotary cement kiln presents the same problem of wasteful operation which has caused the abandonment of its use in this way in other industries. The combustion of pulverized coal requires the use of too great an excess of air to allow high economy.

2 The heat balance under the heading "distribution of heat in kiln per barrel of clinker burned" appears to be misleading and is apparently inaccurate, as item 3, where 147 256 B.t.u. are charged to heating 384 lb. of clinker to 2600 deg. fahr. and item 4, which accounts for loss of heat in the same weight of clinker, assume this clinker to be discharged at 1380 deg. fahr. and cooled to approximately the atmospheric temperature of 70 deg. fahr. I contend that the clinker was never heated to a temperature much, if any, above 1380 deg. or the temperature at which it was discharged. The author states also, that the observed temperature 2 ft. inside the nose ring was 2400 deg. fahr. It is therefore quite impossible to conceive such a great reduction in temperature while the material was traveling in the hot end of the kiln through a vertical distance of approximately 2 ft. It is not fair to assume that the clinker acquires a temperature equal to that of combustion in the furnace.

3 The clinkering operation must of necessity be slightly exothermic and the high heat influence of the clinker zone is only necessary to bring about the chemical reaction of the fusing of the lime and

silica. I have found that lime in the presence of silica becomes chemically active at the temperature at which the lime is formed and as soon as it is formed in the furnace. Thus if we had a kiln long enough and which supplied only sufficient heat to accomplish the calcining and should maintain the lime and silica at this calcining temperature for a sufficient length of time, we would obtain clinker; but the clinker forming reaction would proceed with a degree of rapidity corresponding to the heat under which the reaction took place. In an electric furnace the clinker forming reaction is nearly instantaneous.

4 Considering the production of cement in a rotary kiln, the burning operation, so called, should be divided into steps when considering the utilization of the heat. Where the wet process is employed the operation might be divided into three steps; that of drying, calcining and clinkering. In the dry process, which is most commonly employed, it should be divided into the steps of calcining and clinkering, and in view of the fact that the clinkering operation is exothermic in its character it is evident that the utilization of heat in the kiln can almost wholly be charged to the calcining step. This is a low heat operation and in my experience, extending over several years in calcining operation, I have discovered that calcining can best be done by the application of the heating agent and the generation of the heat where it is to be used rather than with pregenerated heat.

5 There is great room for improvement in the burning of cement clinker, as we are attempting to conduct in a single furnace two heating operations which are diametrically opposed. Under existing conditions we are performing the operation of calcining, which requires the heat of the fuel for the satisfaction of the endothermic reaction by a heat treatment which is entirely unsuited; and providing a combustion suitable for the final or clinkering step, which absorbs but little, if any heat.

6 An ideal flame for calcining is a long flame of low heat intensity by which the heating agent is applied where it is to be used. This has been evidenced for many years in lime burning where until a few years ago it was almost impossible to produce a good quality of lime economically with coal. Wood was employed with much better results, due to the long flame produced therefrom, this flame reaching in and around the material to be calcined. Several years ago I tested some lime kilns and noted that a cord of wood in the same kiln produced more lime than a ton of coal, although the thermal value of the coal was twice that of the wood, ton for cord. The temperature of the escaping gases at the top of the kiln was in both instances about equal

and an analysis of these gases showed substantially complete combustion in both cases.

7 I immediately set about to produce what might be termed a wood flame from the coal by regulating the duration of the combustion or the temperature and volume of flame produced therefrom. The atmospheric proportions of oxygen to neutral gas were changed by the admixture of waste gases from the top of the kiln, and by reducing the percentage of oxygen in the atmosphere thus used to about 12 per cent, with the result that a longer flame was produced than could be secured from wood under ordinary conditions with natural draft. The long flame produced about twice as much lime with a given amount of coal as had been produced under ordinary conditions, thus obtaining about the same thermal efficiency with the oal as had previously been obtained with the wood fuel.

8 The lime kiln, by the way, affords a most interesting device for the study of combustion, as it is probably one of the most efficient. I have recorded 87 per cent efficiency in the tests of such a kiln. This long flame theory has been applied with great saving of fuel in industries where comparatively low temperatures over large areas were sought. Of course, such treatment would not do at all in steam practice.

9 My theory is that fuels differ one from the other (leaving out of consideration the question of relative thermal values), mainly as their velocities of combustion differ, or as they more or less readily combine with air. We are too liable to judge of fuels from the thermal value standpoint, which is proper in steam practice, but not where a fragmental mass of large area is to be heated and the heat evenly distributed.

10 The operation of calcining with the liberation of CO_2 from $CaCO_3$ commences at about 752 deg. fahr.; while the calcining of $MgCO_3$ requires an inappreciably small amount of heat, and even though the calcium carbonate under treatment is in a fine pulverulent form, the duration of the calcining process cannot be forced by the application of high heat but must be allowed to proceed slowly. This is especially the case where silica is present, as the subjecting of the carbonate of lime with the silica to too high a temperature causes melting of the silica when lime is not present, forming clinker. I am also convinced that less heat is required for calcining when silica is present.

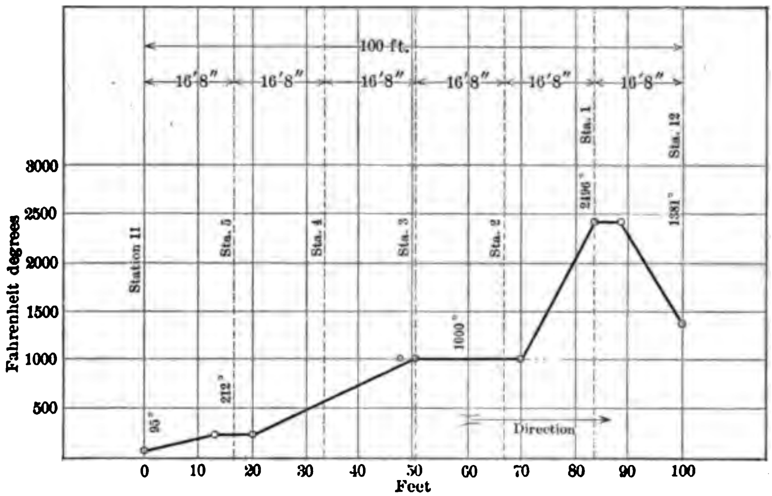
11 The author has raised the often debated question as to what should be the length of the new long kiln. I am of the opinion that we should use the long kiln for calcining purposes only and conduct

the clinkering or exothermic operation in a separate kiln designed to be operated with regenerative checkers, utilizing producer gas for fuel. This question could be easily settled, as the economical length of the calcining kiln would be regulated by the temperature of the escaping gases, which should be the lowest possible. At present, where the two operations are conducted in one kiln, it is necessary to withdraw rapidly the products of combustion from the front of the kiln to allow for the rapid evolution of heat from the stream of fuel which must be burned with short duration so as to produce high localized temperature. A division of the process will, I believe, allow the use of heat regenerators for the final step, and the use of producer gas, hitherto unsuccessful, will obviate the grinding of coal. By the regeneration of air for calcining only and the use of a low temperature long flame in a long calcining kiln, I believe that stack gases can be brought down lower than 200 deg. fahr. in both steps and nearer the theoretical amount of air used to support combustion which would mean, among several other benefits, a great saving in fuel.

THE AUTHOR Considerable difficulty was experienced a short time ago in making tests upon a kiln in which an electric LeChatelier pyrometer was used for observing temperatures. Holes were drilled at certain intervals throughout the length of the kiln, porcelain tubes inserted and the temperatures read. It was practically impossible to observe the temperature of both the gases and materials in the kiln; the temperatures were taken while the kiln was revolving and the tubes were broken because of the materials striking them. At one or two stations, however, we obtained the exact temperatures of the materials which were of course considerably less than the temperature of the gases at the same points. Fig. 1 and Fig. 2 show the curves plotted from the results of these previous tests, giving the exact temperatures of the gas and the probable temperatures of the material and we do not believe the temperature of the material will vary more than 100 to 200 deg. in the higher temperatures than those stated. This test was made on a 100 ft. kiln, using the ordinary wet process, and analyses were made of samples taken at each point where temperatures were observed. The temperature of the clinker was observed by inserting the porcelain tube of the pyrometer in the pile of clinker after it was discharged from the kiln.

2 The point Mr. Eldred makes of dividing a kiln into two parts and using the kiln proper for calcining purposes only, and producing the clinkering results in a specially designed kiln, can be answered

in this way: The tendency of the successful Portland cement manufacturer is to concentrate all operations into as few steps as possible and *practical;* in other words, to *simplify* the process by installing as few machines and equipments as are necessary to produce the desired results. In a "wet process" or a "semi-dry process" plant the long kiln combines three different operations in one, namely; drying, calcining and clinkering, and it has been proved by actual experience that the long kiln is far more economical in point of production and cost in the drying operation than the installation which operates a preliminary dryer for the raw mix before it enters the kiln proper, and it is a question in the writer's mind, if figured in pounds



Note:- Temperature at Station 11; 1; 12; actually observed

FIG. I

MAXIMUM TEMPERATURES OF MATERIALS IN 100 FT. BY 6 FT. BY 7 FT. KILN (CALCULATED FROM GAS TEMP.)

of coal per barrel, which of course must include the increased horse power necessary to operate the special klin for clinkering, whether the cost of operating the two independent kilns would be less than the cost of operating the long kiln.

3 Referring to Professor Carpenter's discussion: To the writer's personal knowledge, over 10 per cent of the Portland cement made last year was manufactured by what is known as the "semi-dry process;" in other words, sufficient water was added to the ground raw material to enable a perfect uniform mixture to be made before the material entered the kiln. There are many instances in the manufacturing business today in which the engineer must make

concessions to the manufacturer, and this is one of them. If a company has been operating for some time, producing a superior article and enjoying the reputation of never having had this article rejected, it is going to take a strong argument to induce them to make an important change in the process of manufacture of that article. In the Lehigh Valley, what is called cement rock is used almost exclusively for the manufacture of Portland cement; in this rock nature has intimately mixed, far better than man could do, the two requisite materials necessary for the manufacture of Portland cement, namely, limestone and shale, or calcium and silica. In certain cases, possibly 5 per cent of either material is added in order to make the analysis of the raw material perfect. Because of this intimate mix, the

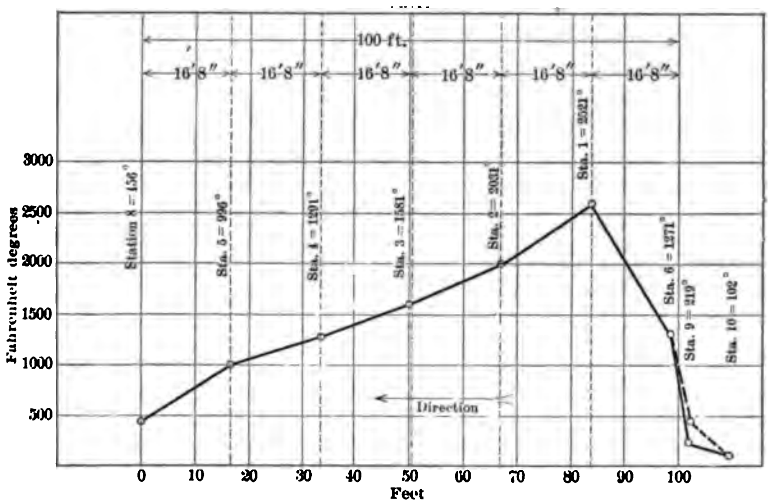


FIG. 2

MAXIMUM TEMPERATURES OF GASES IN 100 FT. BY 6 FT. BY 7 FT. ROTARY KILN

material burns at a lower temperature and at a correspondingly lower fuel consumption per barrel than in the case where two independent materials, such as limestone and shale, or marl and clay, are ground and mixed and burned into Portland cement clinker. At one time it was thought impossible to produce a Portland cement by the mixture of two independent materials such as these, but the industry has grown, and just as good Portland cement is manufactured west and north of the Lehigh Valley as is made in any of the original plants. Theoretically the actual amount of heat necessary to evaporate the amount of moisture added to the raw mix may exceed in cost the loss in stack dust, increased horse power necessary to grind the raw material from 3 to 8 per cent finer in the case of the "dry process," but it may be difficult to produce a clinker through the dry process and operating on two independent materials, which would remain absolutely uniform the year round.

4 Relative to Professor Carpenter's criticism: that the results for the 60 ft. kilns were extremely poor, we beg to refer him to Par. 9, and Par. 16 of the original article. The short time test on a plant may look good on paper, but it is the long time test which proves whether or not a plant, though *theoretically* perfect in one case and *practical* in the other, is *financially* successful. The maximum capacities of the kilns, of course, were observed, but the test includes shut downs, repairs, inclement weather, etc. In the case of the long kiln 600 barrels were produced in one day, and the maximum limit was very much beyond this; in other words, it was impossible to feed sufficient material into the kiln.

5 Relative to the stack temperature of 1300 deg. fahr. of the 60 ft. kiln, the writer has observed in many instances, in Michigan, in the "wet process," stack temperatures of from 1000 to 1500 deg. fahr.

6 There was no intention of being unfair to Professor Carpenter in stating that his system of using waste gases from the kilns under boilers was impracticable. The statement was based upon the fact that to our knowledge only two plants using this method are in existance at the present time, and the second one to adopt it is now constructing a third plant in close proximity and installing the long kilns. It may be said in favor of the system, however, that in some cases the cost of tearing out the short kilns and installing the long ones would be prohibitive and the boilers might be installed but only under the most favorable conditions. In a modern up to date Portland cement plant *simplicity* is the watch word. Much machinery and special apparatus may look good on paper and operate successfully *part* of the time, but they cause shut downs and delays and do not produce cement *all* the time.

No. 1146

COST OF HEATING STORE HOUSES

Comparison with Cost of Dry-pipe and Calcium Chlorid Sprinkler Equipments

By H. O. LACOUNT, BOSTON, MASS.
Non-Member

In the work of the Associated Factory Mutual Fire Insurance Companies the problem of protecting store houses and their valuable contents against fire has required careful study. In nearly all classes of manufacturing properties experience has conclusively demonstrated that the automatic sprinkler, supplied with ample water, is the best means of protection. As is generally known, the automatic sprinkler has an orifice about ½ inch in diameter which under normal conditions is closed by a valve held in place by links or struts, so arranged that on the melting of some fusible solder the valve is liberated and water immediately discharged. For the average case, a temperature of 160 degrees fahr. is sufficient to open a sprinkler and the great work which the automatic sprinkler has done in reducing fire losses comes from the fact that it stands ready night and day instantly to deluge a fire with water at its start. The records show that the majority of fires are held in check, or even extinguished, by the opening of less than a half dozen sprinklers.

2 Long experience showed that store houses used for holding large amounts of cotton, wool, hemp, jute, together with the manufactured articles made from these stocks, and many other miscellaneous products, needed protection to prevent bad losses in much the same way that manufacturing buildings needed it. And again the automatic sprinkler was found the best device.

3 The larger part of the store houses, however, are not heated, so that in winter, water in the sprinkler pipes would freeze. This led to the development of several types of automatic valves which would permit draining water from the sprinkler system during cold weather

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and filling the pipes with air under pressure. The valve, ordinarily known as a "dry-pipe valve," was so designed that on the opening of a sprinkler and the escape of the air, the valve would let in the water. Experience again has shown that with valves of certain types, properly cared for, reliable sprinkler protection can be obtained in this way, and a large number of such equipments have been put in.

4 Dry-pipe valves add appreciably to the first cost of the equipment. They require frequent attention while in service, and there is necessarily a delay, averaging perhaps a minute, between the opening of a sprinkler and the discharge of water, which means where there are inflammable contents, that the fire may spread, opening more sprinklers than would have been necessary had the first one instantly deluged the small blaze with water, the result being excessive water damage. Again, there is always the chance of a system being put out of commission for some time due to water freezing in the pipes in case they were filled and could not be promptly drained. For these reasons, it has always been considered preferable to have the full water pressure constantly on the heads, and this raised the question of the possibility of economically warming store houses just sufficiently to prevent freezing.

5 There was no question but that as a rule brick store houses could be warmed more easily and therefore at much less expense than those built of wood, but just what it would cost was not definitely known. This, therefore, became the subject of investigation, and in 1901 the matter was referred to the Inspection Department, which is the engineering bureau for the Mutual Companies, and the work was carried on under the author's direction.

Two methods of procedure presented themselves;

a Apply certain formulae previously developed by several eminent German engineers and frequently used in such cases;

b Determine definitely by test the actual cost in one or more heated buildings.

6 In most calculations of heat required the normal inside temperature has usually been assumed to be about 70 degrees fahr., varying from say 50 degrees for rooms in which persons exercise vigorously to say 75 to 80 degrees for such rooms as in hot-houses. However, in store houses it is only necessary to maintain the temperature a few degrees above freezing, and as there seemed to be but few data on record from actual tests of such buildings it was decided to make tests as there was opportunity.

DIFFERENCE BETWEEN TEMPERATURES INSIDE AND OUTSIDE OF STORE HOUSE

7 In 1901 we did not know of any heated store houses where a test could be made of the actual amount of steam required to keep the temperature in such buildings above freezing, say at 40 to 45 degrees fahr., and therefore as a preliminary step, a series of tests was carried on during the winter of 1901–1902 in several store houses in different parts of the country to determine the average difference between the outside and inside temperatures of *unheated* buildings when used in the ordinary way for store house purposes.

8 It was assumed that the temperature inside light wooden buildings would necessarily closely follow the outside temperature and therefore this class of building was not included in the test, but only those of brick in which an appreciably higher inside temperature might be expected. However, buildings of different sizes were chosen to see what influence this item of cubical contents might have on the relative inside and outside temperatures, and by selecting store houses in different sections of the country a wide variation of weather conditions could be studied. With these points in mind the following mills were asked to coöperate in carrying on tests in buildings mentioned: Lewiston Bleachery & Dye Works, Lewiston, Me.; Nashua Manufacturing Company, Nashua, N. H.; Johnston Harvester Company, Batavia, N. Y.; Hamilton Manufacturing Company, Lowell, Mass.; Mount Vernon-Woodberry Cotton Duck Company, No. 1 Mill, Baltimore, Md. In every case the mill managements were very ready to give their assistance, and to them and to those men at the several plants who took the readings, looked after the thermometers, and kept the records, the credit for the success of this part of the work is very largely due.

9 Each mill was sent a Draper recording thermometer to be hung inside the store house; a maximum and minimum thermometer to be placed out of doors near the building, and a dated, loose-leaf note book, in which was to be recorded (twice a day), the readings of the outside thermometer, direction and force of wind (light, moderate, strong), condition of weather (fair, cloudy, snow, rain) and approximately how much of the time the outside doors were open. The dial from each recording thermometer, giving a week's record of inside temperature, together with the leaves from the note book corresponding to that week, were returned weekly.

10 From these data temperature curves were drawn for each store house, see Fig. 1, 2, 3, 4 and 5 inclusive, weather conditions being also

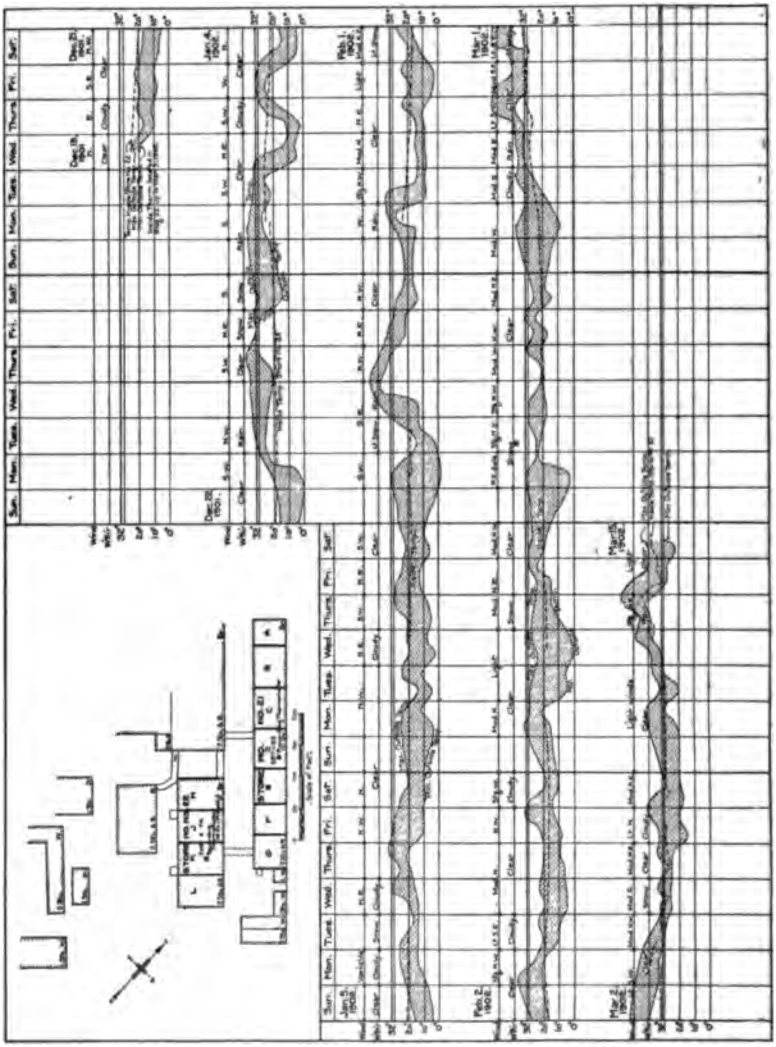


FIG. 1 RECORD OF TEMPERATURES AT UNHEATED STORE HOUSE OF LEWISTON BLEACHERY AND DYE WORKS

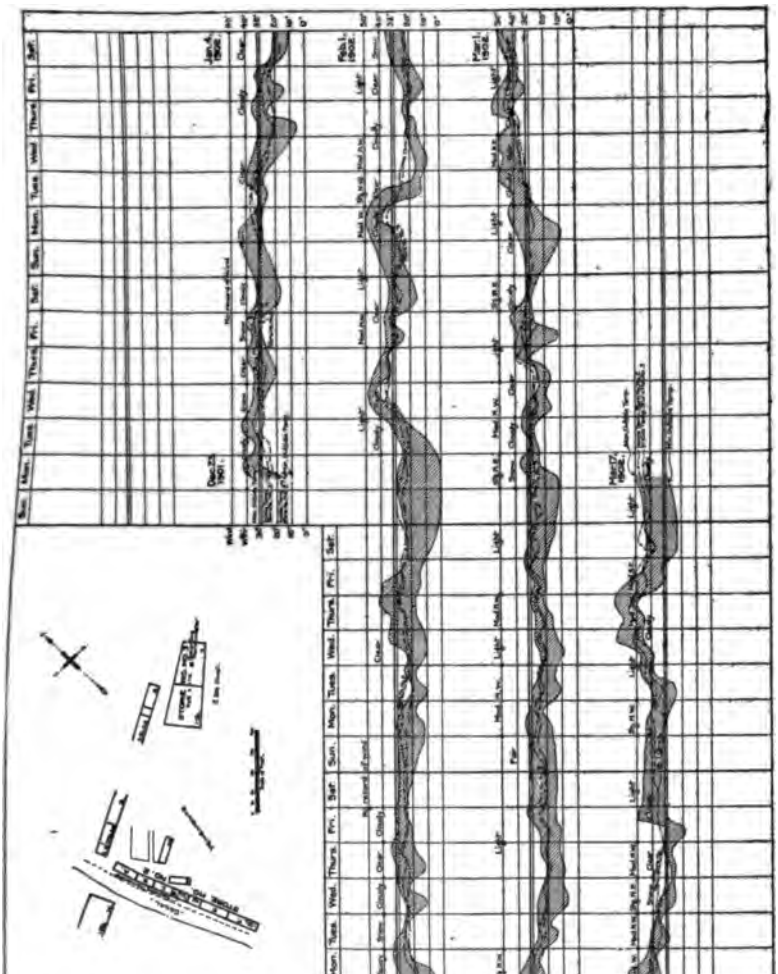
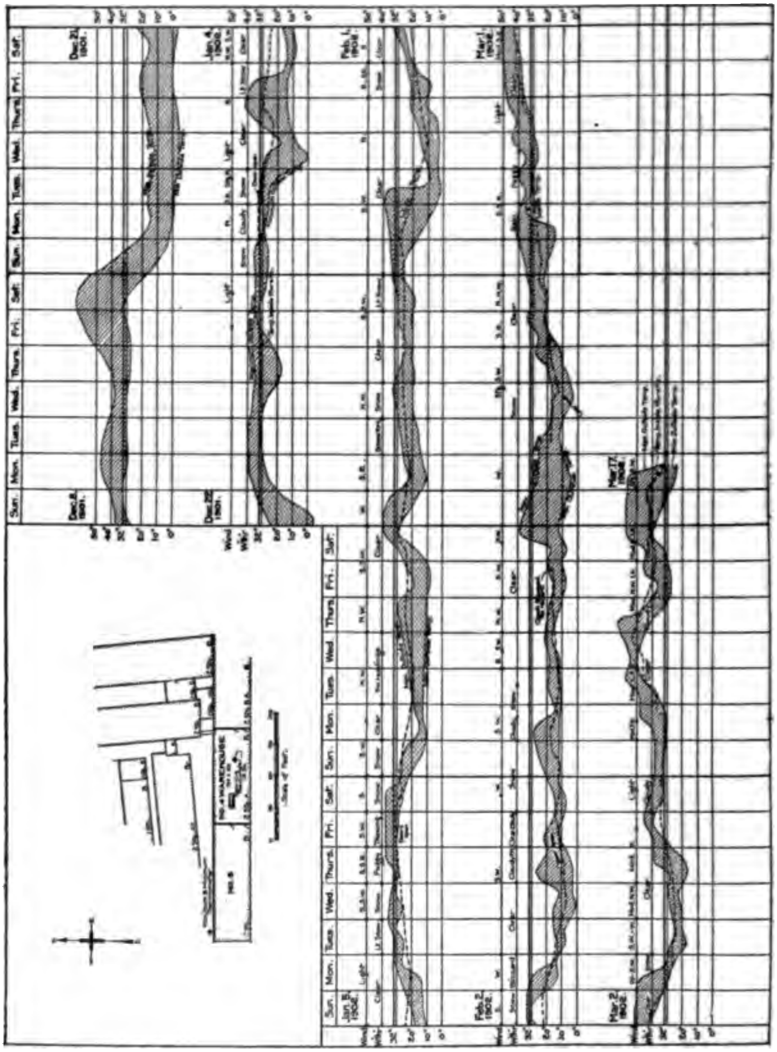


FIG. 2 RECORD OF TEMPERATURES AT UNHEATED STORE HOUSES OF NASHUA MFG. CO.



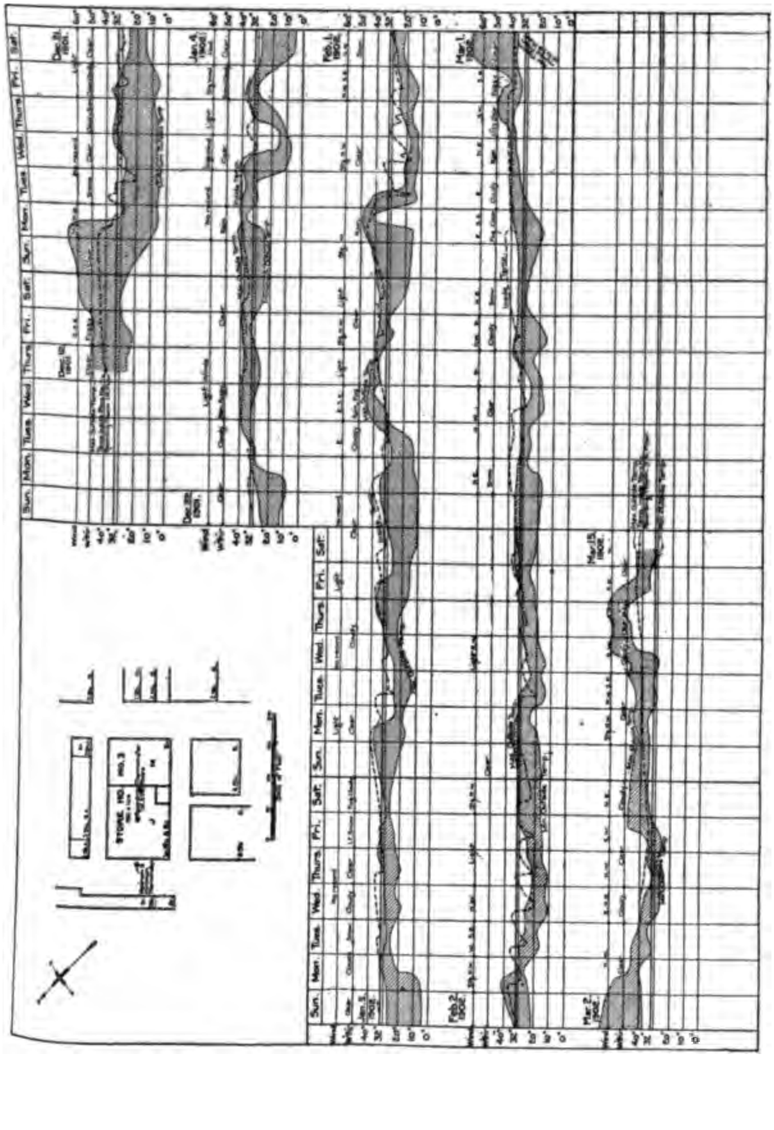
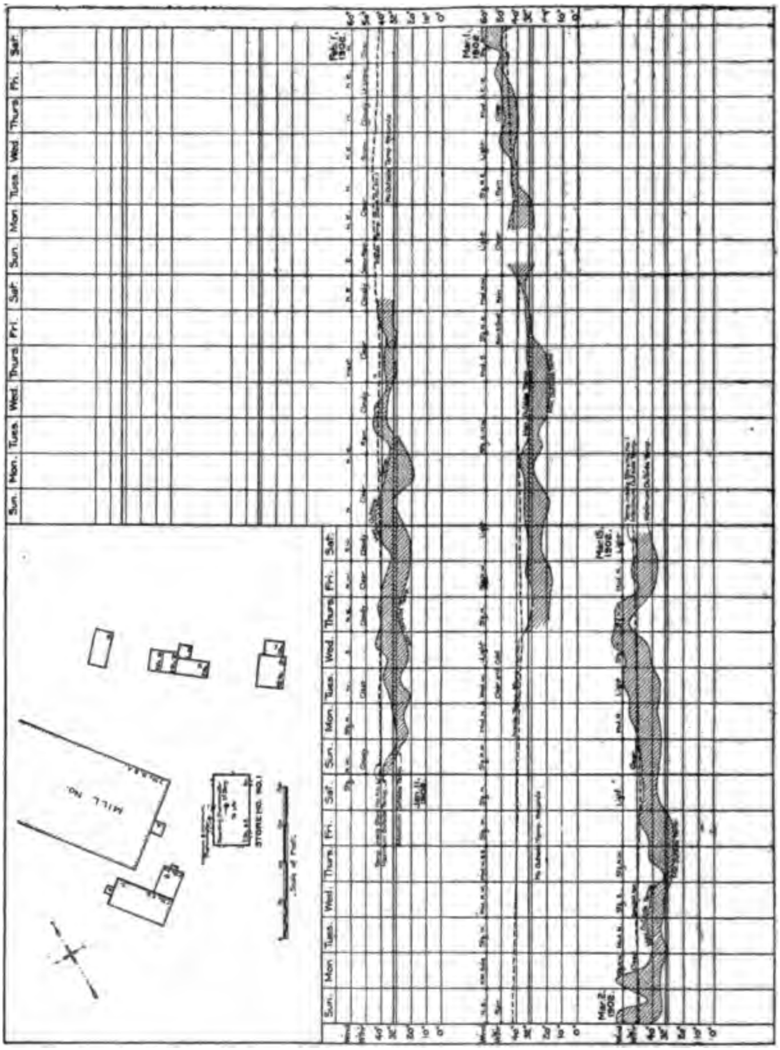


FIG. 4 RECORD OF TEMPERATURES AT UNHEATED STORE HOUSE OF HAMILTON MFG. CO.



indicated thereon. A plan of each property in the vicinity of the store houses under test is also given, showing roughly to what extent, if any, the store house was shielded from the wind by the neighboring buildings.

These curves show that as a general rule:

a The inside temperature changes gradually and does not follow the sudden temperature changes out of doors.

The apparent rapid fall of the inside temperature shown in some of the houses generally took place during the forenoons and undoubtedly was due to the opening of the outside doors.

b The inside temperatures were a fairly good average of the outside temperatures.

With but few exceptions, they never reach either the highest or the lowest outside readings, even when the outside conditions remained reasonably constant for a number of days.

It is to be noted that the temperature inside the brick store house at the Mt. Vernon-Woodberry Cotton Duck Co., Baltimore, Md., kept well above the freezing point throughout the winter.

TESTS OF STEAM HEATED STORE HOUSES

11 During the summer of 1902 No. 3 store house of the Hamilton Manufacturing Company of Lowell, Mass., in which temperature readings had been taken the previous winter, was equipped with steam heating pipes, so that water could be kept on the sprinklers during cold weather. This offered an opportunity to determine the amount of steam necessary to keep the building warm, and the owners were entirely willing to have a test made, which was done in February, 1903.

12 About this time store house No. 22 of the Lewiston Bleachery and Dye Works, Lewiston, Me., in which temperature readings had also been taken during the winter of 1901–1902, was piped for steam, and during the summer of 1903 the large 4-section store house A of the Bates Manufacturing Company, Lewiston, Me., was built and also piped for steam heating. At the Androscoggin Mills, Lewiston, Me., the building known since 1903 as store house No. 6, was heated. These buildings gave additional opportunity to obtain data on the cost of heating, and in each case the owners readily consented to a test. Arrangements were therefore completed for tests in these three store houses in January, 1904.

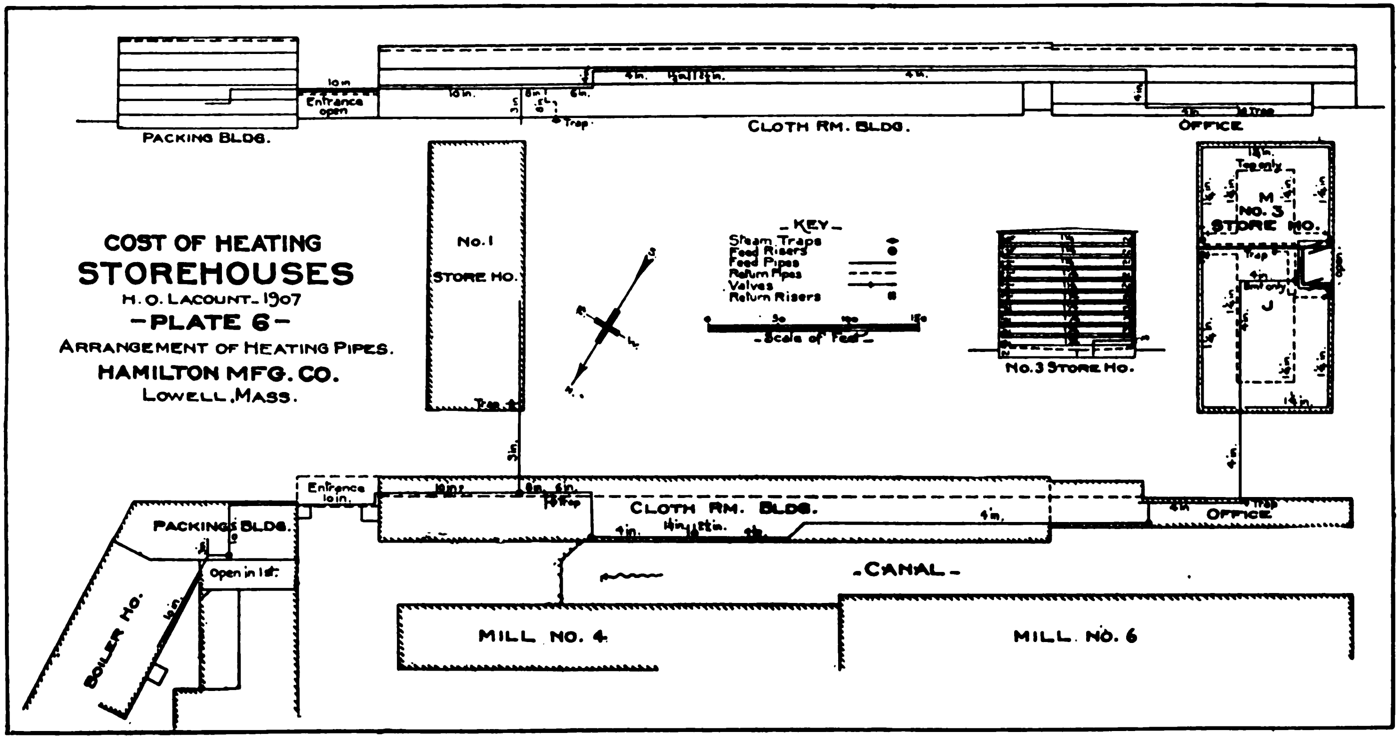


FIG. 6 ARRANGEMENT OF HEATING PIPES HAMILTON MFG. CO.

DESCRIPTION OF BUILDINGS AND EQUIPMENT

13 The above four store houses and their surroundings, also arrangement of steam pipes, are shown on Fig. 6, 7, 8, 9 and 10.

The buildings and heating systems are briefly described as follows:

The Hamilton Manufacturing Company No. 3 Store House (see Fig. 6 and 7) was of brick, plank, and timber construction 100 by 192 ft., ten stories and basement. The building was divided into vertical sections by a blank fire wall. Access to the several floors was obtained through double tin-clad fire doors in a common elevator and stair tower, the tower being open on one side out of doors. The surrounding buildings were comparatively low, affording no wind protection to the upper stories. The building had a large number of windows of small area, made of ordinary glass in wooden frames. There were a few doors on the first floor for shipping purposes in addition to those in the tower. There were numerous cracks in the floors, due to the shrinking of the planks.

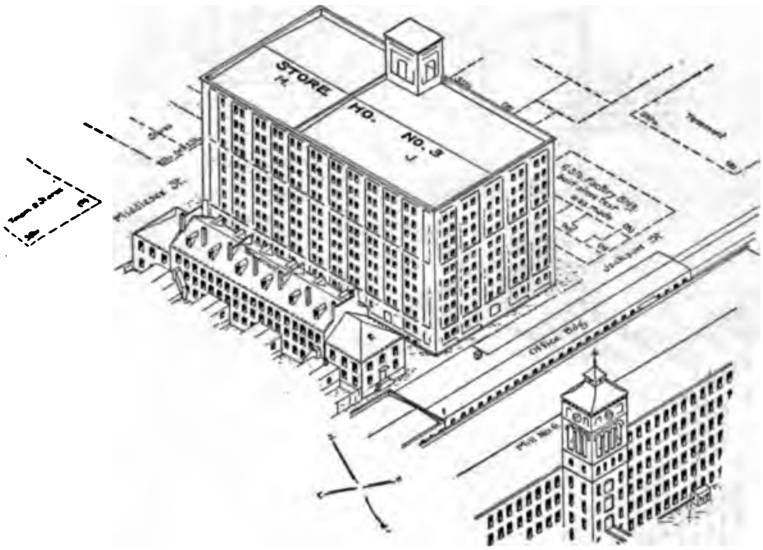


FIG. 7 STORE HOUSE NO. 3, HAMILTON MFG. CO., LOWELL, MASS

14 In the basement was a warm opener room about 100 by 40 ft. which was not included in the test. The other floors contained cotton in bales and cloth in bales and cases, with the exception of two floors of one section, which were vacant. The store house was possibly two-thirds full.

15 The heating system consisted of one line of 1¼ inch pipe near the ceiling, about 3 feet from the outside walls of each floor, with an additional loop in the top floor under the roof. These pipes were supplied from two risers, one in each section, the lower half of each

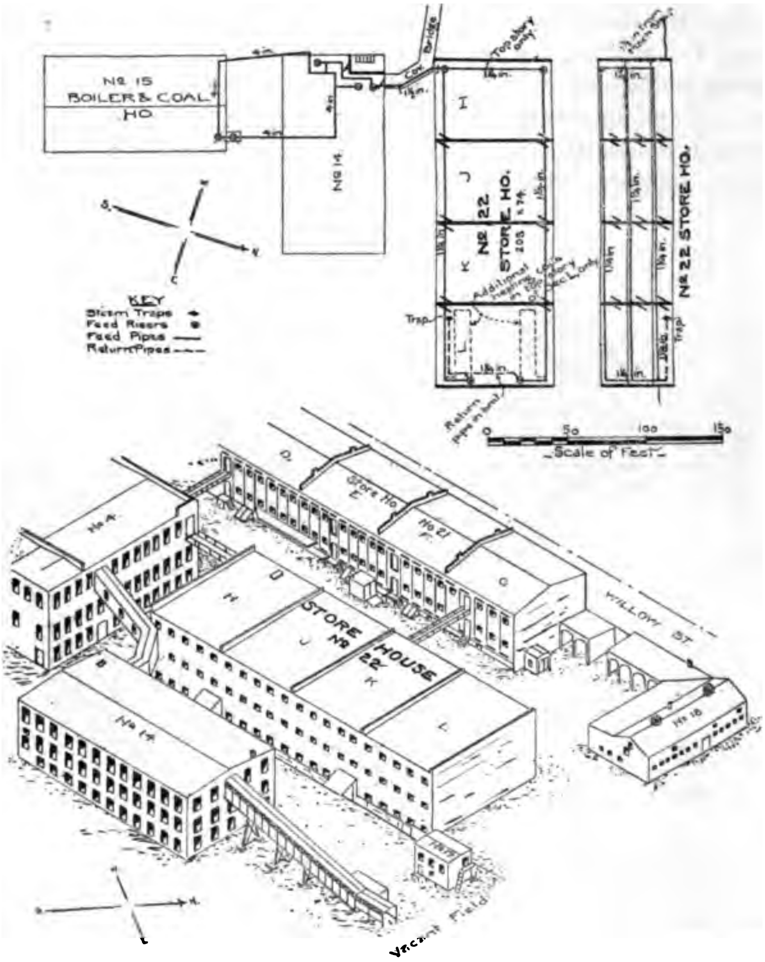


FIG. 8 STORE HOUSE NO. 22, LEWISTON BLEACHERY AND DYE WORKS, LEWISTON, ME.

riser being 3 inches, the upper half 2 inches. The pipes also connected with two drains, one for each section, the lower half of each being 2 inches, the upper 1½ inches. Steam could be cut off from any floor by gates at the risers, and as noted later, approximately every alternate floor was kept shut off during the test, which probably could not have been done had it not been for the cracks in the floors, which allowed the heat from one story to pass into the one above.

16 The steam was taken from one of the main mill supply pipes and tapped at different points for various purposes. The distance

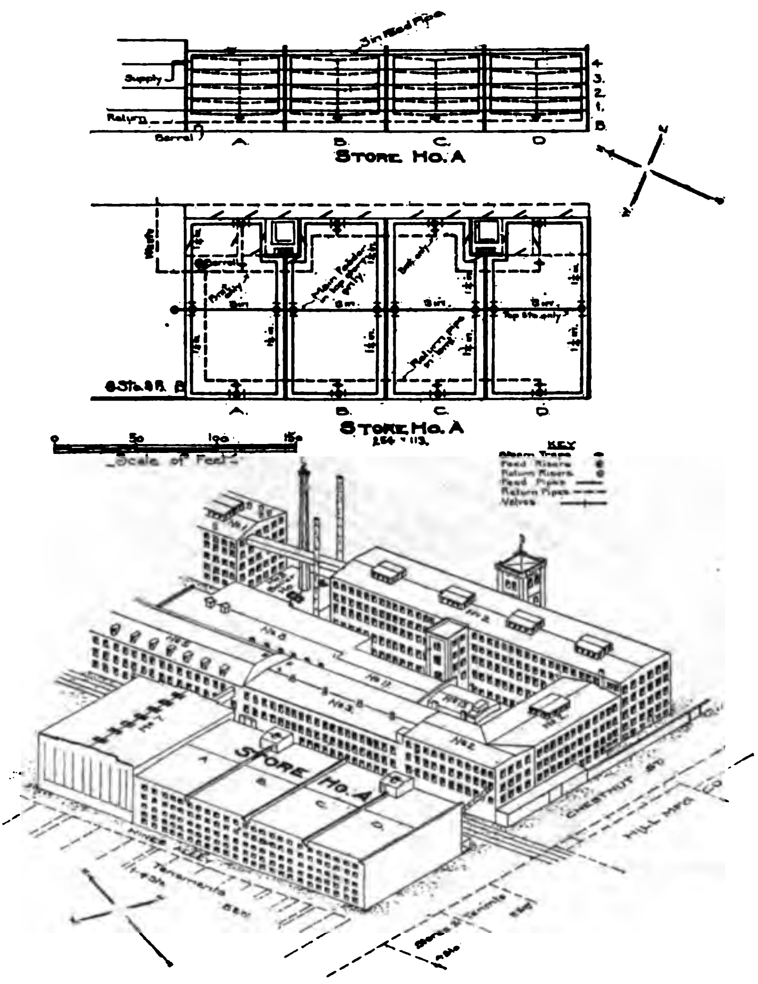


FIG. 9 STORE HOUSE A, BATES MFG. CO.

from the boiler house to the store house along the pipe was about 1200 feet; boiler pressure, 76 pounds; pressure at store house, 50 pounds. By means of a reducing valve at the point of entrance to the store house the pressure in the heating system was kept at 2 pounds or less, by gage, except for a few hours one afternoon, when the pressure was increased to from 6 to 10 pounds in anticipation of an exceptionally cold night. The drain pipes from the heating system were run to one "dump" trap, which delivered all condensed steam into the barrels used in the test.

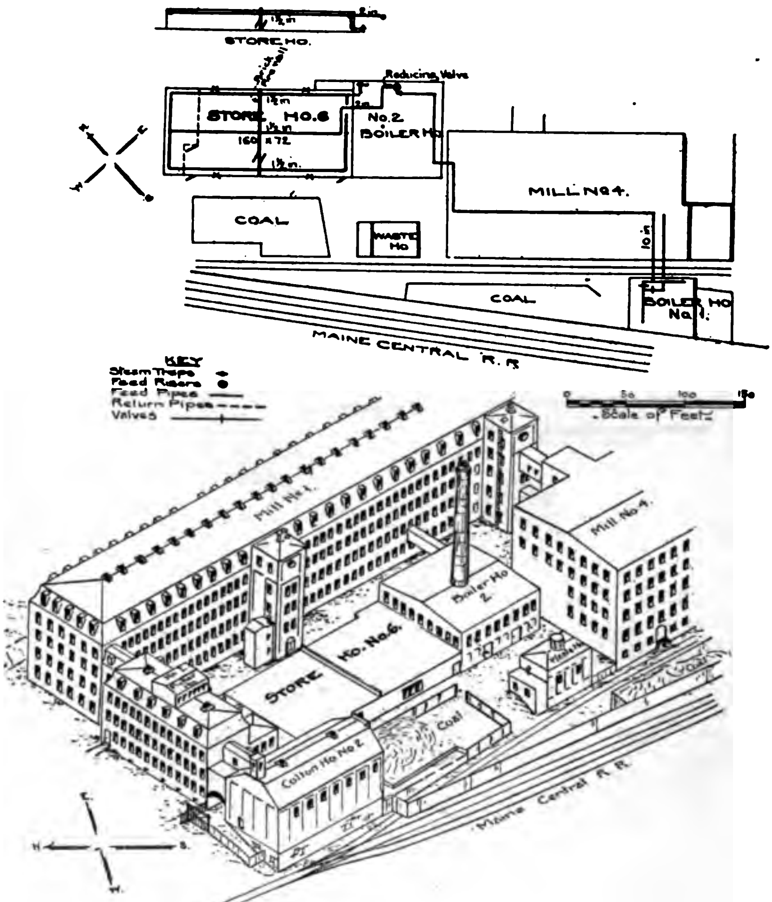


FIG. 10 STORE HOUSE NO. 6, ANDROSCOGGIN MILLS, LEWISTON, ME.

17 The Lewiston Bleachery and Dye Works store house No. 22 (see Fig. 8) was of brick, plank and timber construction, 74 by 280 feet, two stories and basement, divided into four vertical sections by fire walls having double tin-clad fire doors at the openings. There were no openings between the basement and fi st floor but from the first to

second floor were two open stairways and one open chute. The store house was shielded from the wind to some extent by buildings on three sides. The buildings had several windows, but of small area, made of ordinary glass in wooden frames, and there were four or five outside doors; the basement contained chemicals and miscellaneous storage, and the first and second stories contained cotton goods in bales and cases. The store house was about two-thirds full.

18 The heating system consisted of one line of 1¼ inch pipe near the ceiling, a few feet from the outside walls of each story, with an extra loop in the top story of one end section, to take care of the extra cold due to the roof and wind exposure from that direction.

19 The steam was taken from the mill boilers through about 175 feet of 4 inch pipe to a reducing valve in the basement of No. 14 building, thence through about 100 feet of 1½ inch pipe to the store house. The boiler pressure was 80 pounds; pressure in the heating system, 12 to 15 pounds by gage. Both 4 inch and 1½ inch supply pipes above mentioned were covered with magnesia and drained away from the store house. The heating pipes in the store house were drained into a trap which delivered into the barrels used in the test.

20 The Bates Manufacturing Company store house A (see Fig. 9) was of brick, plank and timber construction, 254 by 113 feet, four stories and basement divided into four vertical sections by blank fire walls, access to the different floors being obtained through tin-clad fire doors in the elevator and stair towers. The building was protected from the wind to some extent by surrounding buildings. The building contained numerous windows of small area made of wired glass set in metal frames.

21 With the exception of two warm opener rooms, each 34 by 22 feet, not included in test, the basement was vacant. The upper floors contained cotton in bales and cased goods, and were nearly full.

22 The heating system consisted of one line of 1¼ inch pipe near the ceiling running entirely around each section in each floor, the pipe being located a few feet from the walls. There were two supply pipes and two drain pipes for each section, and a sufficient number of gates were provided so that the heating pipes could be controlled in four divisions in each floor. In addition to the above, three radiators were placed in each section of the first floor along the northeast wall to prevent freezing of the water in the sprinkler pipes near the doors, which were necessarily opened from time to time when making or receiving shipments.

23 Steam was supplied from the mill boilers about 380 feet distant. The steam main for mill service was tapped a short distance from the

store house for a 3-inch supply for this heating system. The boiler pressure was 65 pounds, and at the entrance to the store house 60 pounds during the first part of the test, but during the final test the pressure was reduced to about 10 pounds by throttling the valve at the entrance, no reducing valve having been provided. The system was originally laid out with a trap at the bottom of each vertical drain pipe, these traps discharging into a common return drain. However, they did not operate satisfactorily and were cut out and a large trap was inserted in the common return pipe for the tests, this trap discharging into the barrels.

24 The Androscoggin Mills No. 6 store house (see Fig. 10) was of wood, 160 by 72 feet, one story high, having plank and timber roof and floor, and walls made of two thickness of boards, with two thicknesses of heavy building paper between them, a total thickness of 2½ inches. The building was divided into two vertical sections by a fire wall containing one opening, protected by a double tin-clad fire door. The building had four large windows, protected by outside storm windows. There were also two outside doors. The building contained mostly cotton in bales and was nearly full. The heating system consisted of one line of 1½ inch pipe located near the ceiling, a few feet from the outside walls, and an additional length of 1½ inch pipe through the center of the building.

25 Steam was taken from the No. 1 boiler plant through about 350 feet of 10 inch and 6 inch pipe, where it passed through a reducing valve located in No. 2 boiler house adjoining the store house. The boiler pressure was 95 pounds, pressure at entrance to store house, 15 pounds by gage. The condensed steam was piped to a trap in No. 2 boiler house, which was discharged into the barrels used in the test.

26 In working up the results of the tests on the above heated store houses it has been of interest to note the difference or similarity, as the case might be, between the several buildings and their equipments, and to facilitate comparison the following summary has been prepared in tabular form, giving in parallel columns certain data regarding size and construction of buildings, heating system, etc.

TABLE 1 SUMMARY OF DATA REGARDING HEATED STORE HOUSES

Items	Hamilton Mfg. St. H. No. 3	Lewiston Bl. and Dye Wks. St. H. No. 22	Bates Mfg. Co. St. H. "A"	Androscoggin Mills, St. H. No. 6
Location	One city block	Mill yard	Mill yard	Mill yard
City and State	Lowell, Mass.	Lewiston, Maine	Lewiston, Maine	Lewiston, Maine
Walls				
Material	Brick	Brick	Brick	Wood
Thickness in inches	30 to 16	20 to 16	20 to 16	2½
Size				
Ground plan dimensions in feet	192 x 100	208 x 74	254 x 113	160 x 72
Height above ground in feet	90	38 (av.)	40 (av.)	13
Depth below ground in feet	5	4	6	0
Number of floors	10 & bsmt	2 & bsmt.	4 & bsmt.	1
Sections				
Number vertical	2	4	4	2
Size of each in feet	117x100 75x100,	52 x 74	64 x 113	72 x 80
Doors through party walls	None	1 each sec.	None	1
Stair and elevator tower				
Size in feet	20 x 20	None	2–22 x 22	None
Outside or enclosed	Outside	None	Enclosed	None
Framing, etc.				
Plank and timber	Yes	Yes	Yes	Yes
Width of bays in feet	8	10	8	8
Floor beams in inches	14 x 16	5½ x 15 and 12 x 14	10 x 16	
Floor planks in inches	3	3	4	
Roof beams in inches	10 x 12	3-3 x 12	6 x 14	8 x 8
Roof planks in inches		3	4	2
Cubical contents				
Exclud. tower not heated in cu ft.	1,786,000	646,464	1,275,764	149,760
Exclud. bsmt. and tower in cu. ft.	1,622,800	646,464	942,956	149,760
Per cent bsmt. to total cu. ft.	9	26	26	0
Outside surface exposed to cold in sq.ft.	75,360	36,824	56,028	16,616
Area of roof in sq. ft.	19,200	15,392	28,702	11,520
Per cent roof area to total area	26	42	51	69
Area of walls above ground exposed to cold in sq. ft.	56,160	21,432	27,326	5,096
Windows				
Total number and kind	565 single	109 single	92 single	4 double
Glass area in sq. ft.	3690	1207	1164	128
Avr. area per window in sq. ft.	6.5	11.05	12.6	32.0
Per cent glass area to wall area	6.5	5.6	4.7	2.5
Ratio glass area to cu. contents exclud. bsmt. and tower	1 to 440	1 to 396	1 to 810	1 to 117
Outside doors				
No. of	30	8	10	2
Estimated area in sq. ft	900	344	350	52
Per cent door area to wall area	1.6	1.6	1.41	1.02
Ratio door area to cu. contents exclud. bsmt. and tower	1 to 1803	1 to 1878	1 to 2690	1 to 288
Per cent total door and window area to wall area	8.15	7.23	5.54	3.54

TABLE 1—(Continued)

Items	Hamilton Mfg. Co. St. H. No. 3	Lewiston Bl. and Dye Wks. St. H. No. 22	Bates Mfg. Co. St. H. "A"	Androscoggin Mills St. H. No. 6
Ratio total door and window area to cubic contents (exclud. bsmt. and tower)	1 to 354	1 to 416	1 to 623	1 to 830
Occupancy				
Sections contain	Mostly cotton in bales and cloth in cases	Bmt. chemicals and lumber 1 and 2 goods in cases	Bsmt. mostly vacant, ½ cotton baled and cased goods	Baled cotton
Warm opener room in bsmt. contains	7 openers	No room	Openers	No room
Heating system				
Size of supply pipe in inches	3	1½	3	2
Size of circulating pipe in inches	1¼	1¼	1¼	1¼
Length of circulating pipe in feet	6529	1500	5590	636
Total heating surface including risers and drips in sq. ft.	3006	690	3730	316
Circulating pipe only, sq. ft.	2781	605	2877	316
Per cent circulating pipe in top story	16.3	45	20.8	
Ratio heating surface in top story to area of roof	1 to 39	1 to 44	1 to 40	1 to 36
Ratio total heating surface to cu. contents exclud. tower	1 to 594	1 to 936	1 to 342	1 to 473
Ratio total heating surface to area of roof and walls (expo ed to cold)	1 to 25	1 to 534	1 to 14	1 to 53
Per cent of heating surface used in test	58	100	75	100
Steam				
Pressure at boilers	76	80	65	95
Pressure at st .h.	50±	12 to 15	60 and 10	60
Pressure in st. h. system at reducing valve	1 to 2 (av.)	12 to 15	60 and 10	15 to 17 (av.)
Condition, general average	Superheated	Superheated	Primed	Superheated

METHOD OF TESTING

27 Except at the Hamilton store house, a short preliminary test was made in order to see that the conditions were favorable. This was then followed by the final test, the results of which are given later. The preliminary tests are not included in figuring the cost of steam used, but the readings taken are given. This preliminary test was of value, especially at the Bates store house, in that it showed at once that more steam was being used than necessary, and consequently the steam pressure was reduced for the final test. The tests at the Androscoggin and Lewiston Bleachery store houses, which were started Jan

uary 8, 1904, were discontinued owing to the sudden rise of outside temperature and the prospect of a few warm days. The readings taken, however, are also given.

28 The method of determining the amount of heat used in the buildings was substantially the same in all cases, and consisted in:

a Noting pressure or temperature of the steam as it entered the system.

b Determining the condition of the steam from time to time by calorimeter tests.

c Weighing all condensed steam as it came from the heating pipes, night and day during entire test.

d Noting the temperature of the returned water.

From these data the British thermal units per hour used in heating the buildings could be found.

29 To determine the condition of the steam entering the heating systems of the store houses, tests were made with a "barrel calorimeter." For this purpose a wooden barrel, on scales and provided with a valve at the bottom for emptying, was used. The steam heating system was tapped on the low pressure side of the reducing valve or controlling gate valve by a small pipe, terminating in a short length of rubber hose. In some cases this pipe connection was several feet long and was very carefully jacketed with steam pipe covering to avoid condensation as far as possible.

30 The calorimeter test consisted in first weighing the barrel empty, filling it with cold water and again weighing it, noting also the temperature of the water. Steam was then allowed to blow through the small pipe connection above mentioned until it was warmed and all water had been blown out. The hose was swung into the barrel and the steam allowed to run into the water until a certain amount had been condensed. The steam was shut off, the water in the barrel well stirred, and the temperature noted. This test was repeated several times just before the final test was made.

31 From these data the condition of the steam may be determined by the use of the formula given in "Thermodynamics of the Steam-Engine," by Cecil H. Peabody, as follows:

If the pressure of the steam is p, and the part of each pound of the mixture which is steam is represented by X, while the initial and final temperatures of the water are t' and t'', and the weights of the water and steam are W and w, then

$$X = \frac{W(q''-q') - w(q-q'')}{wr}$$

r and q being the latent heat and heat of the liquid for the pressure p, and q' and q'' being the heats of the liquid for the temperatures t' and t''.

32 If the solution of the above formula shows $X = 1$, the steam is saturated; if greater than 1, the steam is superheated; and if less than 1, the steam is wet. While this method is not accurate it was the only practicable means of securing data on this point and did show roughly the condition of the steam. In most cases the steam was found to be saturated, although occasionally a test would show some priming and at times slight superheating. Therefore, in estimating later the amount of heat used in warming the buildings the steam was assumed to have been dry and saturated throughout the tests.

33 The condensed steam was weighed in two barrels, the return drips being piped into a trap which discharged into either barrel as desired. Each barrel was provided with a cover in order to prevent evaporation and to keep the conditions more uniform. While one barrel was filling, the other was emptied and weighed, this giving the tare, which every time was deducted from the weight of the barrel full. The exact time taken to fill the barrels was also noted, thus permitting an estimate of the apparent rate at which the steam was condensed, that is, pounds per hour.

34 In addition to the above, temperature readings were taken about every four hours in different parts of the buildings. Outside temperature and weather conditions were also noted. From these readings curves have been plotted, Figs. 11, 12, 13 and 14, showing graphically the results obtained.

35 At the bottom of each of these cuts is given a curve showing the British thermal units per hour used in heating the buildings. This curve was plotted as follows:

From the "Tables of Saturated Steam" by Cecil H. Peabody the total heat in B. t. u. of the steam at the pressure at which it entered the heating system was found; also, the heat of the liquid in B. t.u. corresponding to the temperature of the returned condensed steam. The heat of the liquid was then subtracted from the total heat, giving the amount of heat in B. t. u. used in warming the store house, per pound of steam. Multiplying this by the number of pounds of condensed steam per hour gave the total number of heat in B. t. u. per hour consumed in the store house, as plotted.

36 During the tests the store houses were used in the usual way, and the steam was turned on and shut off by the mill employees as they had been accustomed to do, so that as far as the use of the buildings was concerned the conditions during the tests were in no way special and, therefore, were representative of the aveiage service. At the Bates store house the preliminary tests showed that the buildings

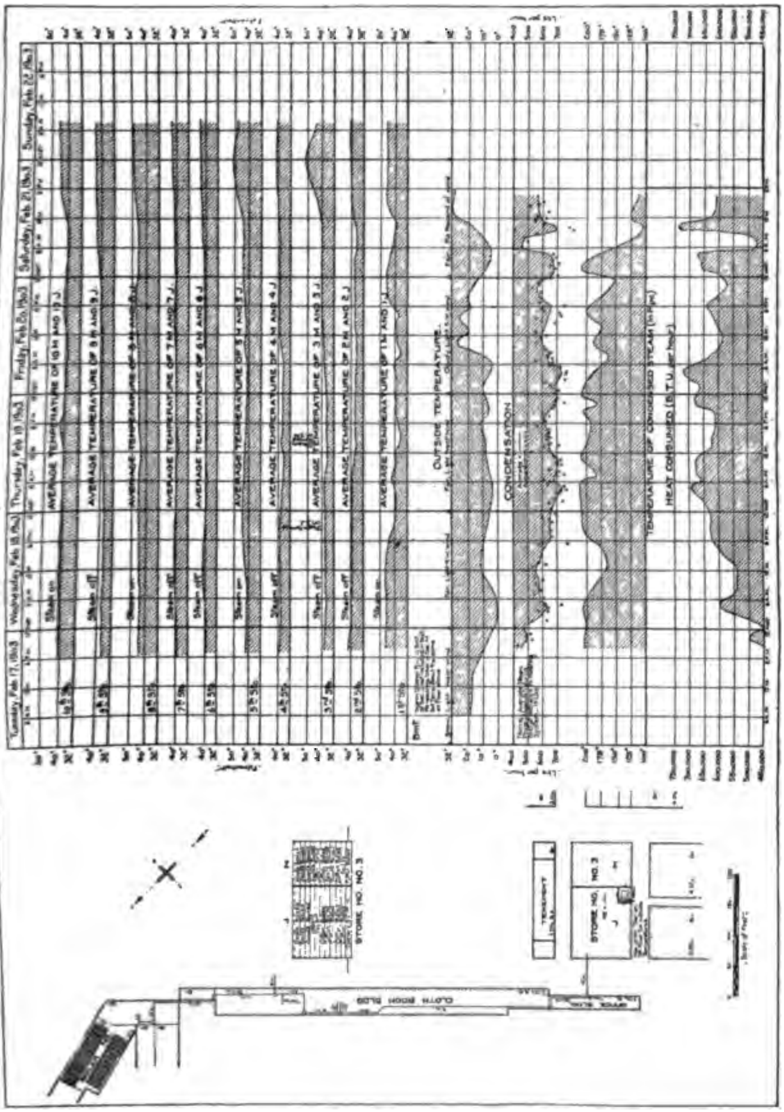


FIG. 11 CURVES SHOWING TEMPERATURES STEAM AND HEAT CONSUMPTION HAMILTON MFG. CO.

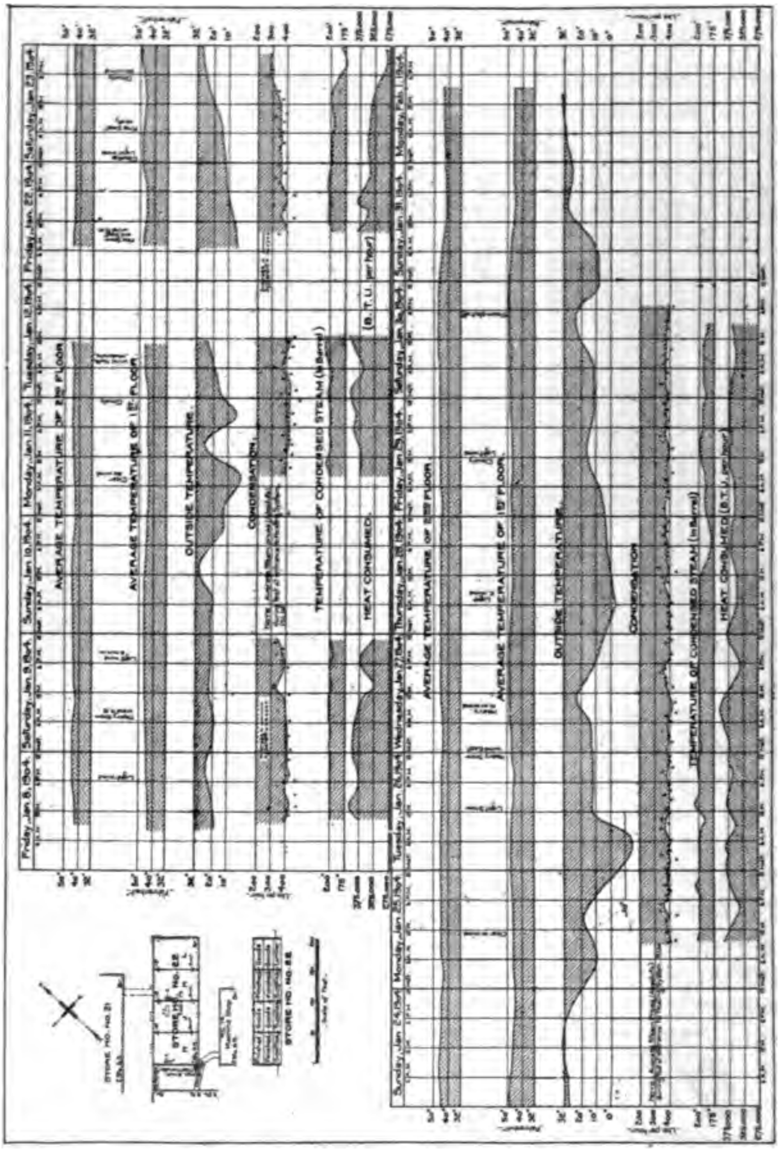


FIG. 12 CURVES SHOWING TEMPERATURES STEAM AND HEAT CONSUMPTION LEWISTON BLEACHERY AND DYE WORKS

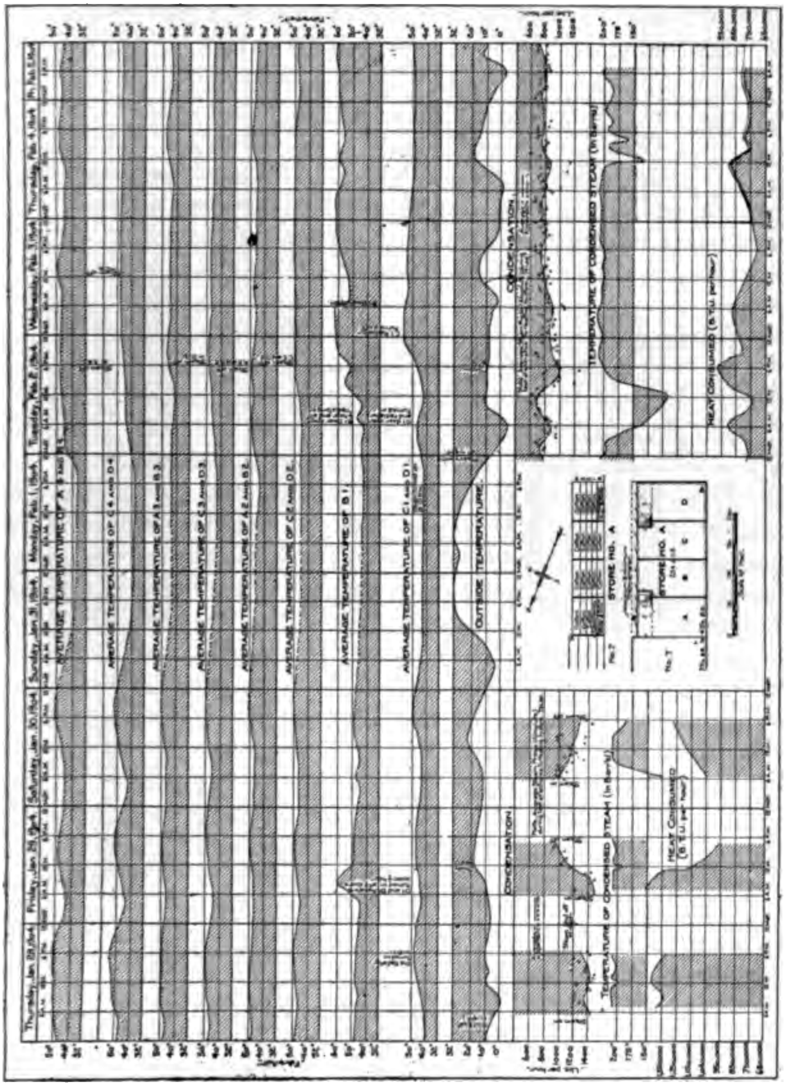


FIG. 13 CURVES SHOWING TEMPERATURES STEAM AND HEAT CONSUMPTION BATES MANUFACTURING COMPANY

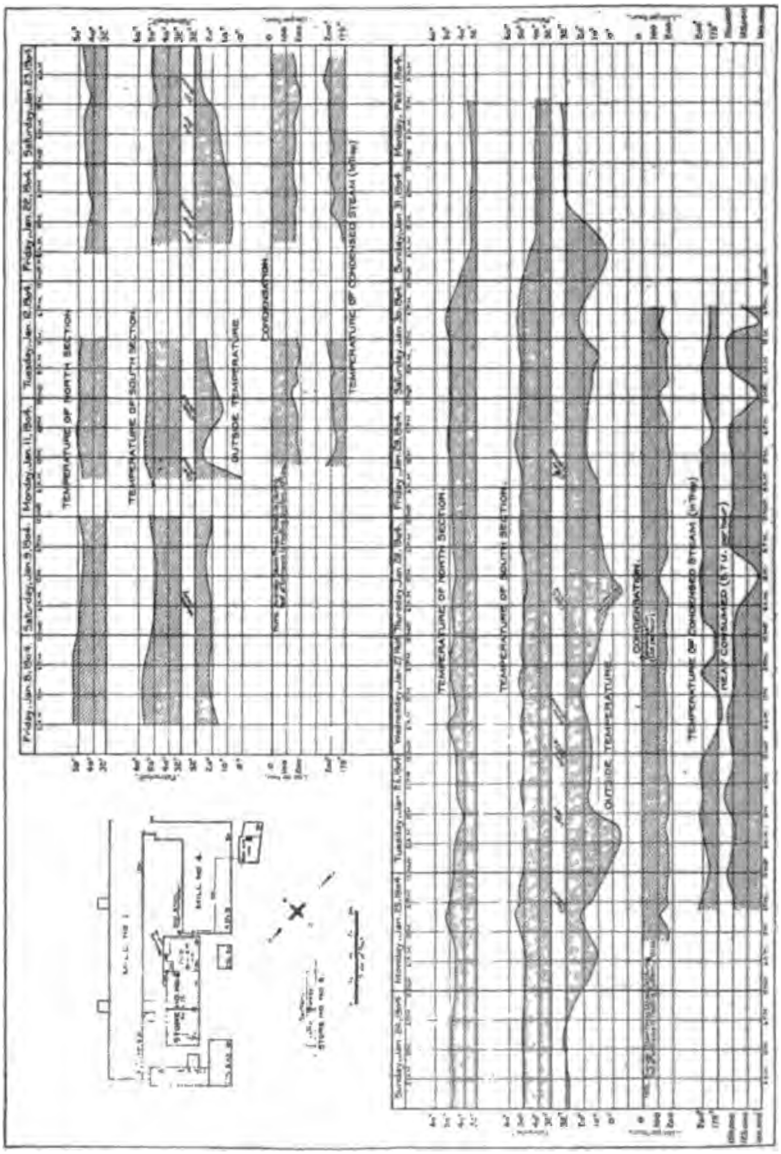


FIG. 14 CURVES SHOWING TEMPERATURES, STEAM AND HEAT CONSUMPTION ANDROSCOGGIN MILLS

were being kept at an unnecessarily high temperature, and a correspondingly excessive amount of steam was being used. In the final tests at this store house the steam pressure was reduced, as previously mentioned, with a view to keeping the temperature, say, between 40 degrees and 45 degrees, which practice was followed after the tests.

RESULTS OF TESTS

By referring to Figs. 11, 12, 13 and 14, it is evident that:

a The temperature inside of each store house was quite uniform in the upper stories, but varied somewhat in the first story, due to the frequent opening of the outside doors for shipping.

b The variation in the steam consumption corresponded roughly to the changes in the outside temperature.

37 Throughout three of the tests, namely, the Hamilton, Lewiston Bleachery, and the Bates, a peculiar action of the steam traps was noted, viz: the frequency of discharge varied widely and at more or less equal intervals, although the conditions in the store house changed only gradually, thus giving a very irregular apparent rate of condensation as shown on the curves. The points plotted show at each weighing of the barrel the pounds per hour, based on the length of time in which the barrel was filling. The irregular discharge was probably due to the traps not entirely freeing the system of water at each discharge, so that it gradually accumulated in the basement piping until the slight increase in head on the traps caused them to discharge more often, with the results mentioned. This would seem to be confirmed also by the curve of "temperature of condensed steam," in that while the traps were operating less often, the temperature of the water discharged was correspondingly lower, suggesting that it had been lying in the pipes longer than when the traps were discharging more frequently.

c While the temperature of the condensed steam varied considerably in some of the tests, the average temperature was about 200 degrees fahr.

d Hamilton store house:

1 The maximum variation of temperature in the first floor was from 32 degrees to 50 degrees, the lower temperature being only for a short time, apparently coincident with the opening of the large outside doors for shipping In the upper floors, the temperature varied from 34 degrees to 51 degrees, the higher temperature occurring several hours after a sudden rise of temperature out of doors.

2 The effect of cracks through the floors is clearly shown, in that alternate floors may be kept sufficiently warm without steam in those floors, although the temperatures were uniformly a few degrees lower in those floors than where the steam was in the pipes.

e Lewiston Bleachery store house:

1 The maximum variation of temperature in the entire store house was from 37 degrees to 59 degrees.

38 These extremes do not show on the curve since only the average readings of a number of thermometers throughout the buildings are plotted.

f Bates store house:

1 The maximum variation of temperature in the first floor was from 45 degrees to 64 degrees; and on the upper floor 37 degrees to 58 degrees.

2 With the store house tightly closed, as during the night and on Sunday, the building cooled very slowly. Therefore it had been the practice to keep the steam shut off during these times, but of course keeping watch of the inside temperature. The tests also show that the store house required several hours with the steam on to regain its normal condition.

3 With about 10 pounds steam pressure in the heating system night and day, the average temperature throughout the store house was substantially the same as when the steam was in the pipes during the day time only,—that is, from 6 A. M. to 6 P. M. but at 60 pounds pressure. It is also of special interest to note that under these conditions, the steam consumption per 24 hours was about 35 per cent greater with 60 pounds steam pressure during the days than with 10 pounds continuously.

g Androscoggin store house:

1 The rate of condensation in the heating system was quite uniform, notwithstanding the considerable variation of outside temperature and a comparatively uniform temperature in the building.

39 Table 2 gives a summary of the inside and outside temperatures and the cost of heating for the period during which store houses were under test.

TABLE 2

Items	Hamilton Mfg. Co. St. H. No. 3	Lewiston Bl. & Dye Wks. St. H. No. 22	Bates Mfg. Co St. H. "A"	Androscoggin Mills St. H. No. 6
Date of Test	1903 Feb. 17, a.m to Feb. 21, m.	1904 Jan. 25, p.m to Jan. 30, p.m.	1904 Feb. 2, a.m. to Feb. 5, m.	1904 Jan. 25, p.m. to Jan. 30, p.m.
Temperature (Degrees fahr.)				
Outside				
Average	12	14	7	14
Maximum	32	24	18	24
Minimum	1	−14	−4	−6
Inside (exc. warm basements)				
Average	41	47	48	49
Maximum	51	59	64	56
Minimum	32	37	43	41
Difference between average inside and outside	29	33	41	35
Average outside for coldest 24 consecutive hours during test	8	3	6½	6
Average inside for same period	40	46	47	49
Steam used				
Total consumption, pounds	56,929	49,282	70,096	20,007
Av. consumption per hr. pounds	612	380	815	156
Average consumption per 24 hrs. pounds	14,688	9,120	19,560	3,744
Av. consumption per 24 hrs. per 1000 cu. ft. of contents, pounds	8.06	14.2	14.8	25.1
Cost of heating				
Estimated first cost of steam pipe installed inc. trap and reducing valve, also 21½ inch gates for each floor of each section. (30 cents per sq. ft. of heating surface)	\$900	\$210	\$1120	\$95
Same per 1000 cu. ft.	\$0.555	\$0.325	\$1.19	\$0.634
Cost of steam to heat st. h. per 24 hrs. (assume 8 pounds of water evaporated per pound of coal, from and at 212 F., price of coal \$4.25 per 2000 pounds)	\$3.90	\$2.42	\$5.20	\$0.99
Cost of steam per 24 hours per 1000 cu. ft. of st. h.	\$0.0024	\$0.0037	\$0.0055	\$0.0066
No. cu. ft. of st. h. heated per lb. of coal per 24 hrs.	884	566	385	319
Average cost of steam per 24 hours per 1000 cu. ft. of store house for the above three brick buildings is \$0.00386.				

40 In order to determine the number of days of winter at Lowell and Lewiston during which the temperature is appreciably below freezing, the U. S. Government Weather Bureau reports for these

cities were obtained for three consecutive years, and the maximum and minimum readings for each day of the winter months have been plotted and the readings for three seasons have been averaged. Similar charts have also been made from the Weather Bureau reports at the nearest Government station to the unheated store houses tested in the winter of 1901–1902, and also for a number of cities in the South, thus giving a general idea of the winter temperatures over a wide section of the country. The daily readings are plotted on Fig. 15 and 16, and the average temperatures for the three years for the winter months at these different localities are given in Table 3 following:

TABLE 3 AVERAGE TEMPERATURE OUT OF DOORS FOR THREE YEARS

November, 1901, to March, 1904
Taken from U. S. Government Records

Location	November 15–30		December		January		February		March 1–15		Average for Dec. Jan. and Feb.		
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max. & Min
Gardiner, Me.......	39	22	32	11	27	4	31	8	42	22	30	8	19.0
Lewiston, Me......	37	23	32	13	26	5	30	9	42	22	29	9	19.0
Nashua, N. H......	40	23	34	14	29	11	32	12	43	24	32	12	22.0
Avon, N. Y........	39	25	33	16	30	13	29	13	43	25	31	14	22.5
Albany, N. Y.......	38	27	33	16	29	13	31	15	42	26	31	15	23.0
Lowell, Mass.......	42	26	36	17	33	13	35	16	47	27	35	15	25.0
Worcester, Mass....	40	27	34	19	30	15	33	17	45	28	32	17	24.5
New Bedford, Mass..	43	29	38	22	34	17	35	19	44	28	36	19	27.5
Baltimore, Md.....	46	35	41	28	37	25	39	25	51	37	39	26	32.5
Cincinnati, O.......	45	33	38	23	38	22	38	22	52	37	38	22	30.0
Richmond, Va.....	57	40	47	29	44	28	45	29	58	40	45	29	37.0
Knoxville, Tenn....	49	33	45	28	45	28	48	30	60	41	46	29	37.5
Charlotte, N. C.....	53	37	48	32	46	31	49	33	61	43	48	32	40.0
Columbia, S. C......	58	40	54	36	50	34	54	37	65	47	53	36	44.5
Atlanta, Ga........	53	38	49	33	48	33	50	35	60	45	49	34	41.5
Montgomery, Ala...	59	40	55	36	55	37	58	40	68	51	56	38	47.0

41 On these charts for Lowell and Lewiston, the period during which the store houses were under test is shown by double cross hatching. From these charts it is estimated that in Lowell an average winter, including only that time during which the temperature is appreciably below 32 deg. fahr., would be represented by 40 days similar to those during which the test was made at the Hamilton store house, and at Lewiston by 55 days similar to those during which the test was made at the Bates Manufacturing Company, and by 60 days similar to those during which the tests were made at the Lewiston Bleachery and Androscoggin Mills. Therefore, multiplying the cost per 24 hours

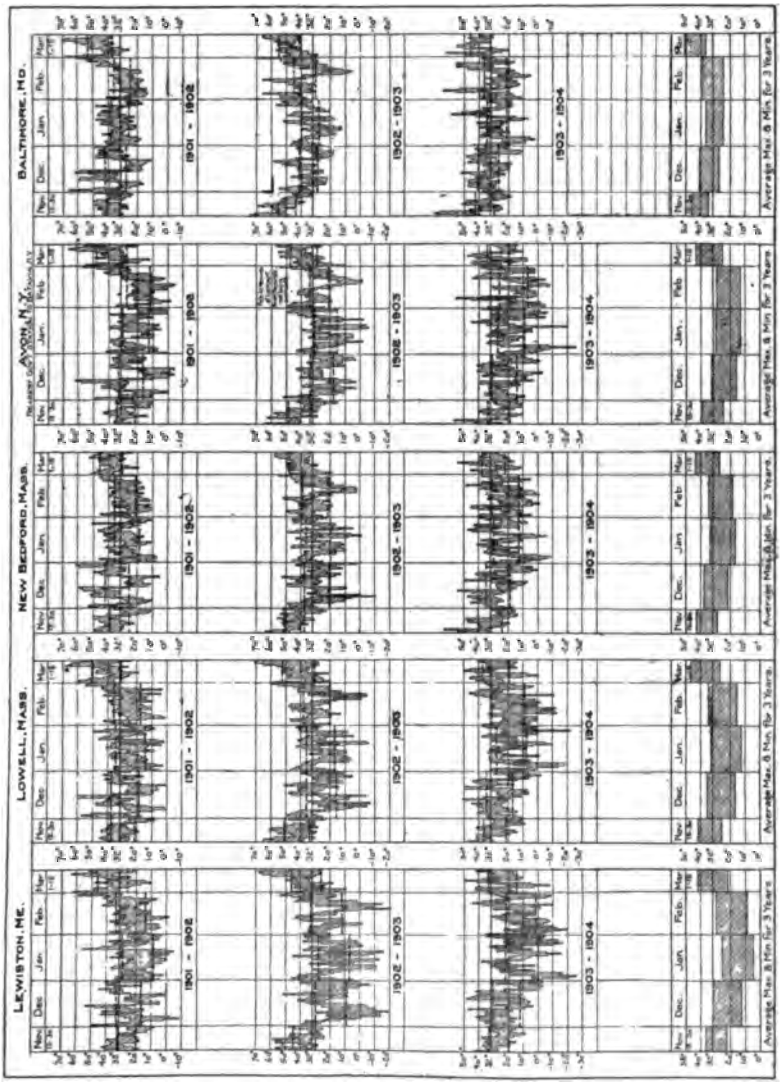
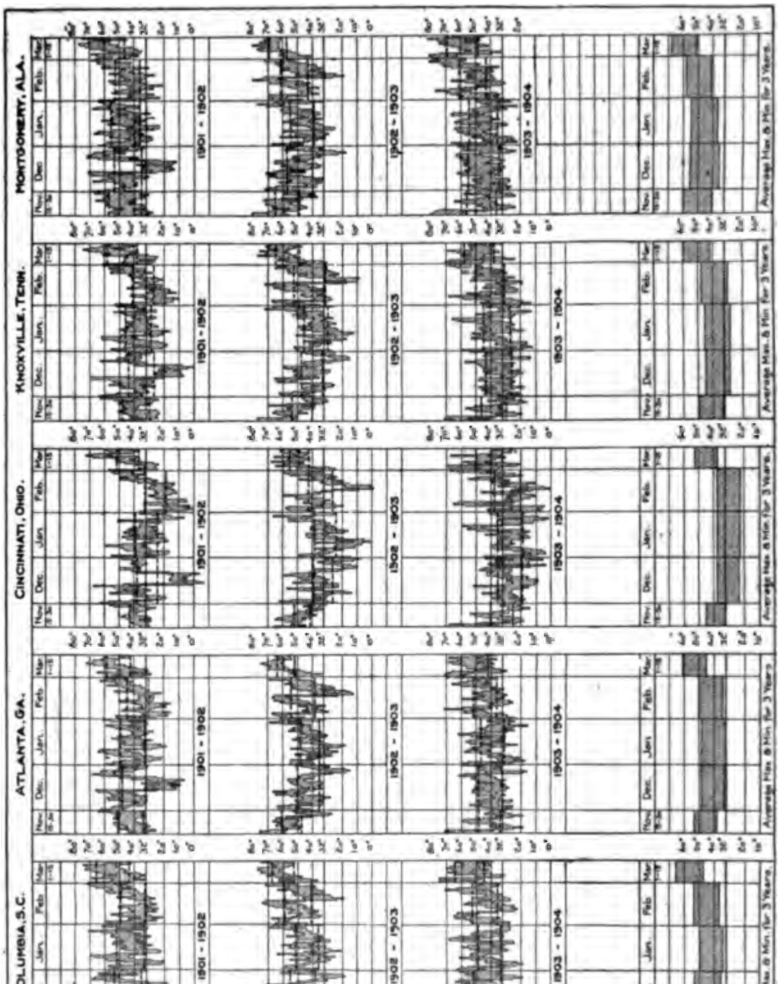


FIG. 15 TEMPERATURE RECORDS IN VARIOUS CITIES


COLUMBIA, S.C.
ATLANTA, GA.
CINCINNATI, OHIO.
KNOXVILLE, TENN.
MONTGOMERY, ALA.
Nov. Dec. Jan. Feb. Mar.
1901 - 1902
1902 - 1903
1903 - 1904
Average Max. & Min. for 3 Years.

obtained from the tests by the above constants, would give the cost for heating these four store houses per winter, as follows:

Hamilton Mfg. Co., No. 3 store house, Lowell, Mass.	$156.00
Lewiston Bleachery & Dye Works, store house No. 22, Lewiston, Me.	145.20
Bates Mfg. Co., store house A, Lewiston, Me	286.00
Androscoggin Mills, No. 6 store house, Lewiston, Me	59.40

42 From the above it will be noted that the estimated costs for the Bates store house is considerably more than that for the Hamilton store house, although the latter building is appreciably larger. This is probably due to the more severe winter conditions in Lewiston and the fact that the inside temperature was kept at a higher point.

S. H. HOWE STORE HOUSE

43 The S. H. Howe Shoe Co., Marlboro, Mass., have a brick store house, 100 by 60 feet, two stories high with boiler house adjoining. This was equipped with a steam heating system and a record kept of the amount of coal used for the winter 1901–1902. The inside temperature, registered by a recording thermometer, seldom got below 60 deg. fahr. and during the night ran as high as 90 degrees. During the winter 89 tons of coal were burned in heating, giving, at $4.25 per ton, the cost of steam for the winter as $378.

44 As the inside temperature was kept much higher than necessary to prevent freezing, this figure is not comparable with those given in the tests for the four store houses above. It is, however, of special interest, as giving some idea of the increased cost where a building is kept at these high temperatures. The Hamilton store house, for example, was about eleven times the cubical contents of the Howe building, so that the cost of heating the Shoe Company's store house per 1000 cubic feet of contents was 26 times that for the Hamilton, assuming as above $156 for cost of heating the Hamilton per year.

PEPPERELL STORE HOUSE

45 The Pepperell Manufacturing Company, Biddeford, Maine, have a one story and basement brick store house, about 150 feet in length and 60 feet in width at one end by 20 feet at the other. During the winter of 1904–1905 they kept a careful record of the amount of steam used in heating by weighing the return water, and estimated that 13 tons of coal were required for the season to keep the temperature in the store house between about 40 to 45 deg. fahr. This would make the cost, at $4.25 per ton, $55. This building has a

cubical content of 97,000 cubic feet, so that store house A of the Bates Mfg. Co. was about 9½ times as large. On a basis of $286 per year to heat the Bates store house, the cost to heat the Pepperell store house per 1000 cubic feet is nearly twice as much. This may be explained in part by the fact that the Pepperell store house was much smaller and the ratio of roof and wall area to cubical contents considerably greater than at the Bates.

ESTIMATED B. T. U., USING GERMAN FORMULAE

46 Having obtained definite information regarding the amount of heat necessary to keep these store houses at the desired temperature, it has been of interest to apply the formulae mentioned in the first part of the paper and compare the actual with the estimated cost. The heat required for each of the four store houses under the conditions of the tests (see Tables 1 and 2) has therefore been estimated using formula $H = k\ (t_1 - t_0)\ S$ and constants as clearly described by Professor J. H. Kinealy, Washington University, St. Louis, in a useful little book entitled "Formulae and Tables for Heating," in which are briefly given the results of careful experiments and the study of the subject by well known German investigators.

$$H = k\ (t_1 - t_0)\ S$$

H =British thermal units per hour. k =constant, value being as given in "Formulae and Tables for Heating." t_1 = average inside temperature. t_0 =average outside temperature. S =area of cooling surface in square feet.

47 Applying this formula to the store houses in question gives results shown in Table 3 following, where are also given for purposes of comparison the figures obtained from the tests.

TABLE 4

Store House	B.t.u. per hr.		Per cent difference
	by formula	by test	
Hamilton Mfg. Co., st. h. No. 3	620,000	626,000	0.97
Lewiston Bleachery, st. h. No. 22	373,000	369,000	−1.6
Bates Mfg. Co. st. h. "A"	682,000	800,000	17.3
Androscoggin Mills, st. h. No. 6........	151,000	148,000	−2.0

48 In the case of the Hamilton and Bates store houses the figures given by the formula were increased 10 per cent on account of exposure, and for the Bates store house a further increase of 5 per cent

was made because of the unusually high wind which prevailed during a considerable part of the test.

49 Table 4 is of special interest as showing how accurately the required heat may be calculated, and the author finds peculiar satisfaction in this close check between the estimated and actual results, believing that the work here described will still further increase the confidence of engineers in the results obtained from using the formula and constants mentioned.

50 In the case of the Bates store house it may be that the outside shipping doors were open more of the time than was noticed, so that a special allowance for this should have been made when applying the formula. If so, this would account for at least a part of the difference between the estimated and actual results.

COST OF DRY-PIPE SPRINKLER SYSTEMS

51 If instead of heating the four store houses where special tests were made automatic dry-pipe valves had been provided in addition to the sprinkler equipment, which would have been necessary if the store houses had not been warmed, the first cost of such dry-pipe valves, valve houses and attachments would have been about as follows, and for easy comparison the first cost of all the heating pipes is also given:

FIRST COST

	Dry-pipe equipment	Steam heating equipment
Hamilton Mfg. Co., store house No. 3	$2580	$900
Lewiston Bleachery and Dye Works, store house No. 22	680	210
Bates Mfg. Co., store house A	1360	1120
Androscoggin Mills, store house No. 6	310	95

52 With a good dry-pipe equipment, the annual cost for care and repairs to the dry-pipe valve and attachments would be small and would ordinarily add little to the yearly pay roll. With steam heat considerable care will be necessary to prevent freezing on the one hand and overheating on the other, and if not given, the waste in steam, due to overheating, will quickly exceed the cost of maintenance of a "dry" system. It is difficult to make exact figures, but it is believed in general that the cost of maintaining a "dry" system would be less than the cost of properly taking care of a store house heating system, and that the totals are not large in comparison with other factors, so that this point need not be seriously considered.

CONCLUSIONS ON HEATING VERSUS A DRY-PIPE EQUIPMENT

53 The data show that the first cost of steam heating pipes would ordinarily be less than the first cost of a dry-pipe valve equipment; also that it will cost more yearly to heat a store house than to take care of its sprinkler system with a dry-pipe valve, but that this cost, even in our colder sections, is a small matter compared with many other expenses for maintenance and operation. In warmer sections the yearly cost of steam would be small and would become an unimportant item. In brief, while heating costs a little more, the extra expense generally would be negligible.

54 Tightness of walls and windows, meaning ability to keep out cold winds, has a large effect on inside temperatures and the cost of heating. In the Southern States no heating would be necessary ordinarily in well built store houses of brick and probably of wood if some special care were taken to make the walls non-conducting and tight, and it is probable that a moderate amount of mason and carpenter work in stopping cracks and making doors and windows fit more tightly would make heating unnecessary in many store houses in these warmer sections.

CALCIUM CHLORID

55 Some attention has been given to the possibility of filling sprinkler pipes in cold buildings with a non-freezing liquid, and calcium chlorid has been suggested for this purpose on account of its several good properties and its low cost. The following somewhat general statements may be made in regard to it.

56 Calcium chlorid ($CaCl_2$) comes in solid or liquid form, and when properly made is absolutely neutral; that is, neither acid nor alkaline. The freezing point of the liquid varies with the strength of the solution and can readily be made so that it will not freeze at temperatures 30 degrees below 0 degrees fahr. The coefficient of expansion is greater than water for ordinary temperatures. A solution freezing at 0 degrees would be 1.175 times heavier than equal volume of water.

57 A chlorid solution has great affinity for water, so that an open pail of it will increase a little in volume in damp weather and decrease when the weather is dry, remaining, therefore, at about the same level all the time, thus making it very useful for fire pails.

58 On account of this property, however, articles wet with it will not readily dry, but if washed with water the chlorid will quickly disappear. Cotton, wool, and textiles, if wet with it, would probably have to be washed to remove the chlorid before they would dry, and

the exact effect of this in affecting salvage is a matter needing further study.

59 In a few cases calcium chlorid has already been used in the sprinkler systems, approximately as follows. In the main pipe supplying the sprinklers is provided a check valve located beyond danger from freezing, with a gate valve above it for draining the system. The gate in the main pipe is closed and the sprinkler system drained. The system is then pumped full of the chlorid solution, and, in order to surely keep the check valve closed and prevent loss of the solution, the pressure in the sprinkler system is raised a few pounds above the normal pressure in the outside supply pipe. The main gate is then opened. It may be necessary to provide small air-pressure tanks for expansion, and occasionally to pump in additional chlorid to make up for waste.

60 The point has been raised that when used in this way, if the check valve separating the chlorid from the public water should leak, the chlorid solution would get into the public supply. It is believed, however, that any ordinary leakage would be small and would quickly become so diluted that unless a drinking water tap were very near the check valve, the condition would not be noticed. Calcium chlorid is, moreover, a somewhat common impurity and not deleterious except in considerable quantities. It is therefore believed that there would not be great difficulty in providing check valves for such work through which there would be little, if any, leakage. As a special precaution, a check valve with two seats and the intermediate space open to the air could be used, but with such a valve care would be necessary that the differential action shall not be sufficient with low-pressure water supplies to allow the column effect of the chlorid solution in the pipes to overbalance the water at ordinary pressure, thus preventing the opening of the valve in case of need.

61 Chlorid solutions in such quantities as would be used in store houses can probably be obtained at an average cost of about 2 cents per gallon, and on this basis the cost for filling the sprinkler equipment in the four store houses where the heating tests were made would be as follows:

Hamilton....	abt. 2220	sprinklers requiring	abt. 2500	gals. $CaCl_2$	costing	abt.	$50
Lewiston	abt. 600	sprinklers requiring	abt. 680	gals. $CaCl_2$	costing	abt.	14
Bates,.......	abt. 1600	sprinklers requiring	abt. 1800	gals. $CaCl_2$	costing	abt.	36
Androscoggin.	abt. 130	sprinklers requiring	abt. 150	gals. $CaCl_2$	costing	abt.	3

62 Calcium chlorid is shipped in liquid form in tank cars holding about 4500 gallons, the strength being such that an equal volume of

water can be added and still get a solution freezing at something below 0 degree fahr. It is also shipped in solid form in iron drums weighing something over 600 pounds. One drum will make about 250 gallons of 0 degrees solution. The freezing point of a solution can easily be determined from its specific gravity.

63 The following table gives the quantity of "Solvay" fused or solid calcium chlorid required to make solutions of given specific gravities and corresponding freezing points, viz:

Specific gravity	Per cu. ft. solution	Per gal. solution	Freezing point
1.250	28.06 pounds	3.76 pounds	−32.6deg.fahr.
1.225	25.06	3.36	−19.5
1.200	22.05	2.95	− 8.7
1.175	19.15	2.56	zero
1.150	16.26	2.18	+ 7.5
1.125	13.47	1.80	+13.3
1.100	10.70	1.43	+18.5

64 If used in a sprinkler equipment, it would be necessary to have enough chlorid on hand, in either liquid or solid form, for one, or better for two or three re-fillings, so that after a fire or a sprinkler break the system could be quickly put again into commission. The solid form can be stored indefinitely in drums, if kept hermetically sealed. It would be necessary to have a tank with each sprinkler system, so that the solution could be saved whenever it is desirable to drain the system for changes or repairs.

CONCLUSION

65 Compared with dry-pipe valves, calcium chlorid would give all the advantages which come from a "wet" sprinkler equipment; less apparatus would be required; no sub-division of the equipment into 300 or 400 head groups would be needed, as is required with dry-pipe work; and the first cost would ordinarily be less. Again, the danger of accidental freezing due to imperfect draining or to some difficulty with steam pipes would be eliminated. A system filled with chlorid would probably require about the same amount of weekly care as a dry-pipe system.

66 The objections to calcium chlorid would be its cost, if there were frequent fires or breaks in the sprinkler system; probably greater water damage on some classes of materials, especially machinery; and the difficulty of making sure that protected properties would always have a sufficient extra supply of chlorid on hand so that after

a fire or a sprinkler break there would not be much delay in getting the system again in service.

67 Finally, with the evidence at hand, it seems probable that calcium chlorid can be used in some places to advantage, and there is at least a possibility that further investigation and experience may show it desirable in an even larger field.

DISCUSSION

Mr. Edward N. Trump Mr. Lacount's very valuable paper on "The Cost of Heating Storehouses" and the protection of sprinklers from freezing will be a great help to manufacturers whose plants and storehouses are equipped with sprinklers.

2 Even where buildings are heated, severe winter weather may reduce the temperature below the freezing point in exposed portions, especially when they are unoccupied at night, during severe storms, and an exposed section of piping, or a few sprinkler heads will freeze. Several hours afterward, when a change in temperature occurs, the sprinklers open and water damage results.

3 Even in sprinkler systems equipped with air valves the condensation of a little moisture from the air in the pipes may deposit enough water in the sprinkler, so that when it freezes and thaws it will be broken, or the valve forced from its seat.

4 The "dry systems" with air valves require a good deal of attention to keep up the air pressure. It is very difficult to keep the system tight because a small leak is not visible, and almost impossible to find.

5 After the use of three or four of these dry systems for several years, with constant trouble from freezing of the sprinklers, the writer began, about three years ago, the use of chlorid of calcium solution, and replaced the dry valves in one or two large sprinkler sections with this solution.

6 An ordinary check valve was put between the indicator valve on the outside of the building and the sprinkler system, locating it close to the wall or in a pit just outside, so that all of the piping exposed in the building would be beyond the check valve.

7 An expansion tank was provided on the top of the system to take care of the changes in temperature, and was placed at the highest point to act as an air chamber. After one season's experience with this plant, the results were so satisfactory that all of the sprinklers in a large number of buildings and storehouses were filled with the

same solution. These buildings contained 4500 sprinkler heads, divided into 10 sections.

8 An experience of two winter seasons with these sprinklers has proved satisfactory in that no pipes or sprinklers have frozen, and there are no cases on record where sprinklers have given way on account of low temperature. While a few sprinklers have let go in different places, there have been just as many of these accidents in warm weather as in cold. We have, in most cases, made no change in the sprinkler system except the introduction of check valves.

9 We have not found it necessary to add any expansion tanks, and we use a portable tank for filling or emptying the systems. The fire patrol inspects each system (which has a pressure gage near its base and connections for pumping in or letting out the calcium solution) once each week.

10 In case any repairs are needed to the pipes, the solution is drawn off into the portable tank down to a level where these repairs are necessary, or in case the check valve needs examination, the system is drawn off completely empty. After repairs are completed, the solution is pumped in again up to a pressure above the working pressure of the fire mains.

11 If there are violent fluctuations in these pressures, and the check valve is not entirely tight, a very small quantity of calcium may leak back into the mains, or a small amount of water may enter the sprinkler system. As, however, this quantity can only be that required to change the pressure in a system, which is nearly full of liquid, it is very small, and does not sufficiently dilute the liquor to give trouble by freezing.

12 When the pressure gets balanced very nearly right, almost no attention is required. In summer time, the solution may be drawn off into a tank, and the sprinklers allowed to fill with water, or a little may be drawn off, sufficient to compensate for the higher temperature in summer, and pumped in again during lower temperature.

13 A small safety valve could be provided, which could take care of very high pressures, but we have found even this precaution unnecessary. The system of pipes and sprinklers must be made very tight to insure that there shall be no leakage of the calcium solution, but leaks are immediately indicated, and they are easily located.

14 A large office recently equipped in the basement and attic has passed through the winter entirely satisfactorily, and no trouble has occurred, although the sprinklers in the attics are exposed to freezing temperatures for a large part of the time.

15 Calcium chlorid is a very neutral substance. It has an extraordinary affinity for water, and will absorb water until the solution is diluted to nearly 20 per cent calcium chlorid. A fire pail filled with 20 per cent solution will have the same quantity after twelve months. When it is made of a proper quality, with absolutely neutral reaction, neither acid nor alkaline, it has no apparent effect upon any of the metals, or upon anything else, except that leather is hardened somewhat if exposed to a dry powder.

16 The liquid testing 20 deg. Be. containing about 20 per cent calcium chlorid which is used in sprinklers does not seem to affect even leather, because it can absorb no more water from lithium. We have found a solution of 20 deg. Be. the best strength to employ. It has the lowest freezing point, and will stand considerable dilution before it will freeze at the temperatures which are likely to be obtained in store houses.

17 In the cases where sprinklers have opened and the calcium chlorid has been deposited on goods or machinery, the water which follows washes the calcium chlorid away very quickly, and so far we have not found the damage to be any greater than would be caused by water alone.

18 An experiment recently made upon a system having 700 sprinklers in one section, showed that it only required taking out of the system about one quart of the solution to reduce the pressure from 180 down to 130 lb. and pumping in an equivalent amount increased the pressure in proportion.

19 It is evident, therefore, that a small safety valve would take care of all of the expansion to be expected in warm weather without depleting the system sufficiently to make the change in solution of any consequence. The calcium chlorid solution is as good as saturated brine to put out a fire, as it protects the surfaces and prevents rapid ignition.

20 We believe, therefore, that three years experience proves this method of preventing sprinklers from freezing better than any other we have seen, and we are adopting it, not only for the exposed storehouses, but for all of our building, in order to provide against accidental reductions of temperatures.

21 The solution may be very quickly made up from solid calcium in drums, which can be stored in a 40 per cent solution in glycerine drums, or a tank provided to hold the necessary quantity for a sprinkler system, and this would be useful to save the calcium when it is drawn off from the system for repairs.

22 No other change will be provided except the check valve,

and a connection for pumping in the solution, and a small pressure gage with ½ inch safety valve to relieve the pressure in case it gets too high.

Mr. J. H. Kinealy Mr. Lacount has drawn some conclusions from the results he has obtained, but he has omitted what to me is the most important conclusion to be drawn from the heating of these buildings. Under his first conclusion on the Bates store house, division 3 of Par. 38 he says: "It is also of special interest to note that under these conditions, the steam consumption per 24 hours was about 35 per cent greater with 60 pounds steam pressure, during the day than with 10 lb. continuously." The conditions are using steam at 60 lb. during the day only and allowing the building to cool at night, and using steam at 10 lb. continuously day and night. The conclusion means that the saving is due to the use of the steam at the lower pressure.

2 The results shown in Table 1 and Table 2 for the brick buildings condensed to the following give important information.

TABLE 1 AND TABLE 2

	Hamilton Mfg. Co. St. H. No. 3.	Lewiston Bl. & Dye Wks. St. H. No. 22	Bates Mfg. Co. St. H. "A"
Pressure in steam heating system at reducing valve, from Table 1.......	1 to 2	12 to 15	60 to 10
Cost of steam per 24 hours per 1000 cubic ft. of store house from Table 2...	$0.0024	$0.0037	$0.0055

3 These buildings are all of brick, and the results show that in the first, steam was used at a pressure of 1 to 2 lb., and it costs 2.4 mills to heat 1000 cu. ft. of space for 24 hours; in the second, steam was used at a pressure of 12 to 15 lb. and the cost per 1000 cu. ft. of space for 24 hours was 3.7 mills, and in the third steam was used at a pressure of 60 and 10 lb. and the cost per 1000 cu. ft. of space was 5.5 mills for 24 hours.

4 If Mr. Lacount had conducted some of his experiments with steam at a pressure below that of the atmosphere he would have found that the cost of heating would have been as low or lower than a pressure of 1 to 2 lb. He has verified what those of us who have had to do with heating work have known for some time, namely, the lower the temperature of the heating medium the greater the economy.

5 It is gratifying to me to know that the results of the calculations

made using the constants given in my book check so well with the results of Mr. Lacount's experiments, and I hope that Mr. Lacount will at some future time carry these experiments further and give us the results of his work.

Mr. W. F. Hendry I have read with considerable interest Mr. Lacount's paper on the comparative initial and operating cost of a dry pipe sprinkler equipment, and a wet pipe equipment with steam heat to prevent freezing.

2 Though the conclusions drawn do not specifically state, the general impression received by the reader, is that the author favors the latter arrangement; and where the warehouse to be protected is adjacent to the main mill buildings, several practical considerations arise tending to substantiate such a conclusion.

3 Few realize how little heat when properly applied is necessary to prevent the freezing of water in well constructed brick buildings in this latitude. I have found it necessary on two occassions to provide sufficient heat for this purpose, in the accomplishment of which the inconsiderable amount required was particularly noticeable, and it is gratifying to note similar results from the work of other investigators. That the cost of such heating, as stated in the paper, is ample to produce the results, is confirmed by the writer's experience in the two cases mentioned.

4 The entire problem is however based on the use of live steam: a method which, while doubtless necessary in many plants, can hardly be considered as representing the average conditions throughout the manufacturing industry.

5 Factories situated where water power is available are not comparatively numerous. The prevailing factory power equipment is a non-condensing steam plant, in which case exhaust steam may be used during the day, thus materially reducing the cost of heating the warehouse. Although quite true that frequently not all the exhaust, but considerable live steam is required to adequately heat the occupied buildings, yet close investigation usually shows that this condition exists only in the most severe weather. It is therefore a point to be considered when comparing the two methods of equipping a warehouse with sprinkler protection.

6 That the dry pipe valve is an added complication is denied by few, and bearing in mind the duties of the average factory power plant attendant, one has little doubt that he will be more familiar with a heating equipment than with a dry pipe valve. A dry pipe system requires an air compressor, the cost of which presumably is

included in the author's estimate of initial expense. If located in the main buildings, a line of pipe must be run to the store house; or if located in the warehouse power must be transmitted to the compressor. In either case contingencies may as readily arise effecting this connection, such as a heating pipe, the disabling of which for an hour or so would not be attended with serious consequences. A pipe conveying compressed air is more liable to stoppage during cold weather than is a steam pipe.

7 It is indeed possible that "the cost of operation and maintenance of a good dry pipe equipment" may "add little to the yearly pay roll," but close association with a small system of some 300 heads, where it is not unusual to see three or four men looking for an air leak by the candle method, leads to the opinion that in ordinary practice it is not so inexpensive as might from this statement be inferred. A network of piping may be, apparently, perfectly tight when filled with water, and yet when drained and filled with air under 50 lb. pressure, a leak may be evidenced by a gradual loss of pressure. A dry pipe valve is usually arranged to operate if the pressure falls to 10 lb., which means that the piping must be so tight that the pressure will not fall to that point during the night; yet a loss of five or ten pounds an hour is not unusual, and detecting so insignificant a leak is sometimes a matter of several hours, during which time the air compressor must be run continuously.

8 Where the system is operated as a dry pipe equipment during the entire year, trouble of this nature is not so prevalent, but the cost of operating the average dry pipe equipment can scarcely be considered a negligible factor in the comparison.

PROF. WILLIAM D. ENNIS From Table 2, which gives the average cost of steam per 24 hours per 1000 cu. ft. of building as $0.00386, the cost per cubic foot for a heating season of 150 days, with coal at $4.25 per ton net, is 0.058. This was for store house heating, in which the average temperature maintained was only 46 deg. It is frequently desirable to have a rough method of estimating the cost of heating a building. Under ordinary conditions, in the vicinity of New York, 1/10 cent per cubic foot will pay for the coal burned in a season. The heat consumption is easily computed from the formula $H = k\ (t_1 - t_0)\ S$, mentioned by Mr. Lacount, which in this case we apply, not to the transmission through the building walls, but to that between the steam and the room, through the heating surface. The difficulty is in fixing on a proper value for k. As it happens, the paper under discussion furnishes an experimental determination of this factor, as is shown below:

Store house	t_1	t_0	S	H	k
Hamilton..............	217	41	1745	626 000	2.04
Lewiston..............	247	47	1500	369 000	2.68
Bates..................	239	48	4190	800 000	1.49
Androscoggin..........	252	49	636	148 000	2.31

2 In this tabulation, the values are taken, t_0 from Table 2, from Table 1, H from Table 4, and t_1 from the steam table for the pressures of steam given in Table 1. The value of S is obtained by multiplying the total amount of radiating surface by the percentage used; both of which data are given in Table 1. The Bates store house gives a result which is out of line with the other three. The only apparent reason for this is that the steam in this test was wet. If we take as the determined value of k the average of the remaining three tests, we have $k = 2.34$. The commonly used value as given by Briggs for a room temperature of 60 deg. is 1.8. This would seem to be too low, especially as these storehouse experiments were made with a rather low range of temperatures.

3 The estimated cost of the heating systems is based on 30 cents per square foot of surface. This figure is presumably for such conditions as existed three or four years ago, and for a rather simple form of heating system. Today the cost would be nearer 60 cents than 30 cents for either direct radiation, or the equivalent in fan units with overhead distribution. Both vacuum apparatus and underground distributing ducts add largely to this cost. Taking 60 cents as an average figure, this is equivalent to 6/10 of one cent per cubic foot heated for the average factory building: the fuel cost for operation being approximately, as stated, 1/10 cent per year. The relation of these two figures is quite important, as affecting the replacement of live steam heating systems by exhaust. Where an equipment investment, as in this case, can show at the outside a gross saving of only 1/6, or 17 per cent on the expenditure, it is pretty difficult to get the money. For store house work, taking the ratios of cubic contents to radiating surface given in the paper, the cost of a good exhaust heating system would be at the present about $0.001 per cubic foot of space heated. The cost of fuel for the season, using live steam, being $0.00058, the gross saving by substituting exhaust for live steam would be 58 per cent instead of 17 per cent. The heating system would still cost less than dry pipe equipment, and the question of operating cost would be practically eliminated.

THE AUTHOR Mr. W. F. Hendry is correct in his conclusion that I would certainly favor the heating of a store house in order to permit water pressure to stand on the entire sprinkler system throughout the cold weather, assuming, of course, substantially constructed buildings, as, for example, those mentioned in the paper. I have no doubt that even better results regarding the cost of this heating could be obtained if exhaust steam were used, as also mentioned by Mr. Kinealy.

2 .Referring to Mr. Edward N. Trump's discussion, I think that in his enthusiasm for the arrangement using calcium chlorid he has somewhat over-estimated the difficulties ordinarily experienced in practice with the automatic dry-pipe system. The dry system undoubtedly requires some attention, and I believe this will be found to be true to a greater or less extent with the other alternative arrangements which have been suggested. In any event, there are today a large number of dry-pipe equipments in use which are giving reasonably satisfactory protection and the average equipment does not leak sufficiently to reduce the air pressure at a greater rate than say 7 to 10 lb. per week. Many systems leak appreciably less than this so that in most cases it is not necessary to pump up the systems oftener than about once a week. By heating the building, however, all the advantages of the wet system can be secured at practically the same expense and in some cases at even less expense than that for the ordinary dry pipe system.

No. 1147

AIR COOLING OF AUTOMOBILE ENGINES

By JOHN WILKINSON, SYRACUSE, N. Y.

Member of the Society

The first result always met by the investigator of the air-cooled engine for automobile work is that the motor becomes too hot for proper operation, and therefore the problem has been to find out how overheating manifests itself and how to overcome the fault.

2 Overheating shows itself in a number of ways. The cylinder may become so hot as to reduce the amount of air and gas taken in, resulting in a reduction of power; or the oil may fail to lubricate, causing an increase of friction, which still further heats the cylinder and reduces its power.

3 This has been proved by introducing a non-volatile lubricant, such as graphite, into the cylinder after the power has dropped, and noting the almost instantaneous recovery of the power. This heating may be so great as to expand the piston head to the point where it will seize.

4 The incoming charge may become so heated by the walls and by compression that it is ignited prematurely. This generally occurs at a low engine speed and is indicated by energetic knocking. Monograph indicator cards taken under these conditions show the pressure to have risen very much higher than normal, indicating that a true explosion may have taken place.

5 Fig. 1 represents an ordinary monograph card, and Fig. 2 shows the high initial pressure due to premature ignition from heat.

6 Again, some projection into the cylinder of metal or accumulated carbon, or more often a red hot exhaust valve, may cause a premature explosion at high speed, or even a burning of the charge on entering the cylinder. This may also produce the same effect at low speed as is shown on Fig. 2. It is therefore necessary to apply remedies to obviate as far as possible the above conditions.

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7 In order to keep the temperature of the cylinder walls within working limits, it is evident that the design must be such that either less heat is allowed to enter the walls or more is carried off, or both of these results accomplished.

8 To allow less heat to enter the walls is one of the fundamental principles of the economy of the gas engine, and is best accomplished by reducing the internal surface exposed to combustion to a minimum, which means to design the combustion chamber so that it will be as nearly spherical as possible.

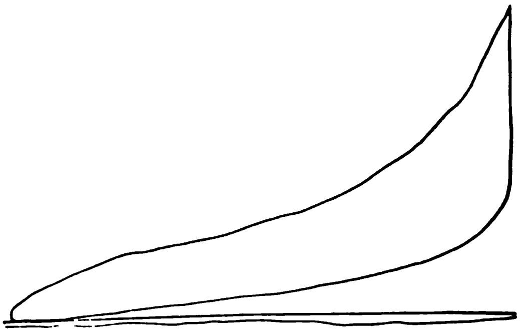

FIG. 1 NORMAL MONOGRAPH CARD COOLED ENGINE UNDER FULL LOAD OF AIR. THIS CARD SHOWS THE EFFECT OF THE AUXILIARY EXHAUST

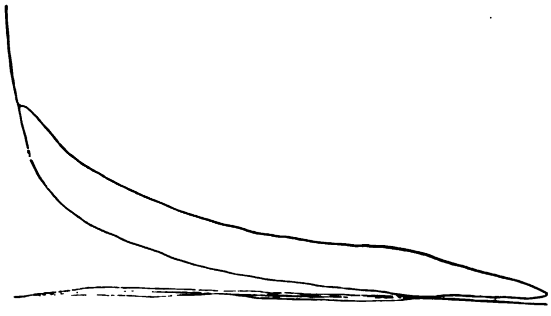

FIG. 2 PREMATURE IGNITION MONOGRAPH CARD DUE TO OVERHEATING OF ENGINE

9 The smaller the internal surface, the less the incoming charge will be heated, the less heat will be lost to the cylinder walls and the less heat must be carried from the walls to keep them at a working temperature. This fact does not seem to be well recognized, and engines are still built with a valve pocket on each side of the cylinder.

10 The internal surface exposed to heat at the time of explosion in a 4 in. by 4 in. motor with a semi-spherical cylinder head is about

38 sq. in.; in the same motor with a valve pocket on either side of the cylinder about 74 square inches, and a good part of this surface has to be left rough. It is evident that the jacket loss must be greater in the latter instance.

11 Engines with a semi-spherical head gain 25 per cent in power and efficiency over the prevalent type with a valve pocket on each side. This type of cylinder head may be machined smooth on the inside to reduce its heat absorbent effect to a minimum.

THE EXHAUST GASES

12 In passing out of the cylinder the exhaust gases often raise the temperature of the exhaust valve to the point of premature ignition, and give up their heat to the metal adjacent to the valve and to the valve passages.

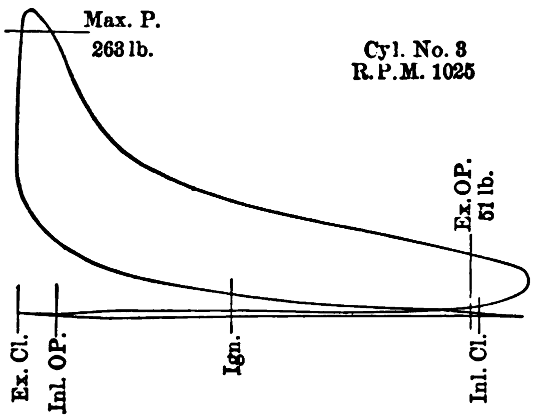

FIG. 3 MONOGRAPH CARD SHOWING EXHAUST WITHOUT AUXILIARY EXHAUST OPENINGS

13 If a port is located at the bottom of the stroke, however, a large part of the exhaust will pass out before the main exhaust opens, and the temperature of the gases passing out at the exhaust valve will be greatly reduced. The exhaust passages contiguous to the cylinder should also be made as short as possible.

14 Fig. 3 shows a monograph card taken from a 4 in. by 4¼ in. engine with an exhaust opening 40 deg. before the end of the stroke. Fig. 1 shows a card of a 4 in. by 4 in. engine, with auxiliary exhaust opening at the same point.

The best internal conditions may be summed up as follows:

a To present the minimum internal surface to the heat.

b To make this surface as smooth as possible.

c To carry off the hot exhaust gases at the bottom of the stroke before the main exhaust valve opens.

d To get rid of what is left with as little surface contact with the cylinder as possible.

e To reduce the friction of piston on the cylinder to a minimum.

f To keep all projections out of the cylinder.

g To make the compression just right to fit all other conditions.

15 The above represent the requirements for air-cooling in regard to the internal conditions of the cylinder as far as the writer understands them. There still remain the external conditions which, except that the more circulation of air the better, have not yielded results that can so confidently be asserted as correct. What the form, position, and material of the outside surface shall be has not been fully decided.

16 If we try to make the cooling surface part of the cylinder casting, we meet great difficulties in the way of unsound casting, insufficient area, and too much weight. If we attach pieces of copper or other good conduction metal in the form of rings or studs, it is very necessary to take care to make an extremely good mechanical joint. No one has yet succeeded in brazing or soldering such material to the cylinder in satisfactory form. An ideal cooling medium would be a finely and equally spaced growth of copper hair metallically joined to the cylinder.

17 A still further complication of cooling is presented by the necessity of using a four-cylinder motor placed longitudinally in the car. Attempts have been made to cool motors of this type by the general circulation of air by means of a fan in front. Each cylinder, however, tends to keep the air away from the next one and to radiate its heat to its neighbor, and the cooling medium gets warmer as it gets toward the rear. It is therefore necessary to increase the cooling surface at the rear of the engine; the third cylinder requiring the most attention, the second somewhat less, and the first requiring very little surface, showing the efficiency of a rapid circulation on an unobstructed cylinder.

18 If a blower is used to drive the air separately over each cylinder, a large amount of power is absorbed by the blower, and a piping system of considerable complication is needed. It also has one of the weaknesses of the water-cooled motor, namely, the danger of ruining the motor by the breakdown of the circulating mechanism.

19 An investigation of the relative sizes of the internal surfaces,

volumes, and speeds of two similar engines for use in an automobile seems to show that the larger the engine the lower the temperature of the cylinder walls. The only parts of a large engine that get hotter than a small one are the exhaust valve and center of the piston.

20 If an auxiliary exhaust port is used, the exhaust valve gets no hotter than in a smaller engine, and therefore the limiting feature of air-cooling a large engine is the temperature of the piston center. The writer has used 4-cylinder engines as large as 5 in. by 5 in. with as much success as smaller ones.

21 In view of the above, it might be asked what can actually be said of the performance of air-cooled motors in practice. A 4-cylinder 4 in. by 4 in. motor with a clearance space of 26 per cent of total volume delivering at the brake:

21 horse power at 1000 revolutions and
27 horse power at 1500 revolutions

or 1 horse power for each 7.4 cubic inches of displacement at 1000 feet per minimum piston speed will positively meet every condition of road use, and we hope to see in the near future 30 horse power at 1000 feet piston speed or 1 horse power for each 6¾ cu. in. piston displacement. This, so far as the writer knows, is as good as is commercially produced in a water-cooled engine of the same size. Tests show the heat efficiency of a motor of this size to be as high as 20 per cent, which represents 0.7 pounds of gasolene per brake horse power hour.

22 It would not be reasonable to assert that an engine can be kept as cool with air as with water and it is not desirable to do so as the efficiency is higher with the hot motor.

23 The air-cooled motor is correct in theory in that it directly cools by the air, and the ordinary type is simpler, lighter and cheaper, and proof against extreme heat and cold. Its cooling is not dependent for safety on any working mechanism. Even with the loss of its fan it can generally be brought to its destination on schedule time. Such faults as it has had have been slowly eliminated. Whether it has any inherent defects which can never be corrected is very doubtful, and its entrance into even the high powered field is only a question of time.

No. 1148

MATERIALS FOR AUTOMOBILES

By ELWOOD HAYNES, KOKOMO, IND.

Non-Member

Since the first attempt to build automobiles, early in the 90's, experimenters have had difficulty in getting materials suitable for the purpose. Steel of high tensile strength was employed but the results were not satisfactory. Lower carbon steels were tried, but they lasted only a few weeks, or months, and then broke short off. Swedish iron did not break, but when the first hard bump was encountered it took a set and the wabbling rear wheels indicated what had happened. Finally a steel of moderately low carbon was introduced which gave only fair results, and if the car was driven for any length of time over rough roads, this also crystallized and broke off.

NICKEL STEEL

2 In 1899 a nickel steel axle was introduced into a machine by Messrs. Haynes & Apperson, and the car made successfully a trip from Kokomo, Ind., to New York, a distance of about 1000 miles, without serious breakage of any kind. This axle was made by the Bethlehem Steel Co., of Bethlehem, Pa., and so far as is now known, was the first material of this kind ever used in an automobile. Nickel steel was used in the axles of cars of this construction for about five years, and not a single case of breakage occurred during that period. Not only was this steel found to be practically free from crystallization, but it possessed a very high elastic limit—about 70 000 or 80 000 pounds—and a tensile strength of over 100 000 pounds, with an elongation of about 15 or 20 per cent.

3 Soon afterward nickel steel was introduced into the construction of driving chains and those chains showed great superiority over the ones formerly made of ordinary steel. When the sliding gears were first used on the automobile for the purpose of changing the gear ratio between the motor and rear axle, trouble was again encountered in breakage.

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Gears were made of the best kinds of tool steel without success. The ends of the teeth would break off when an attempt was made to throw them suddenly into engagement by means of the shifting levers. Trouble of a very serious nature resulted from this, as pieces of the broken teeth would get into the other gears, thus causing them to break, and sometimes the entire train of gears would be almost ground to pieces on account of the breakage first of one gear and then of another.

4 Machinery steel, case hardened, was tried, and while this gave better results, it was by no means satisfactory. The injury and breakage of sliding gears were taken as a matter of course, and almost every person possessing a car equipped with these gears expected sooner or later to make a number of replacements.

NICKEL CHROME STEEL

5 It was finally discovered that an alloy consisting of iron, nickel, and chromium possessed most remarkable properties. Not only could the steel be hardened by heating to redness and quenching in oil, but it could be given a considerable amount of toughness at the same time by drawing the temper somewhat after the first hardening. If the steel was properly made and afterward properly treated, it was found to be almost impossible to break one of the teeth in a 6-pitch gear by means of a heavy hammer. So successful were these gears that they rendered it possible to run an entire season sometimes without the breakage or serious injury of a single tooth. Front axles, steering knuckles, and other important parts requiring high elasticity were made of this steel in certain cars with very good results.

6 It has been found that the manufacturing and working of nickel chrome steel requires great care, as there seems to be some tendency toward segregation when the steel is in the process of making, which gives rise to hard and soft spots in the finished metal. If an attempt is made to manufacture gears from material of this character, it will be found that some of the teeth are extremely hard while others are just about the right hardness. On the other hand, even if the steel is of uniform composition and texture throughout, it will not stand very great variation of temperature without danger of injury, since it is very sensitive to heat treatment. When properly made and properly treated, however, it is perhaps the most resistant substance to shocks and blows yet produced.

7 The following may be taken as a test of high quality nickel chrome steel made by the Krupp Company, of Essen, Germany. It will be noted that much depends upon the treatment of the steel:

DIMENSIONS OF TEST BARS, 5.91 IN. LONG AND 0.59 IN. DIAM.

	Normal	Slightly hardened	Greater deg. of hardness.
Elastic limit, lb. per sq. in.	86,909	148,072	193,589
Tensile strength, lb. per sq. in	111,943	155,326	221,325
Elongation, per cent	14.5	9.1	7.7
Contraction, per cent	64.0	55.6	46.2

It will be noted from the above tests that under the hardening treatment the tensile strength rises rapidly, and the same may be said of the elastic limit. The contraction of area does not suffer so much as the elongation. The comparatively small loss in contraction of area is a good sign, since it indicates that the texture of the steel has been well preserved under treatment.

8 Plain nickel steel containing a very small per cent of carbon is also a good safe material for automobile work. The following may be taken as an example of a mild low carbon nickel steel:

Elastic limit, 65,146; tensile strength, 81,561; elongation, 23.9 per cent; contraction of area, 71 per cent.

9 It will also be observed from this that while the elastic limit is quite low as compared with the nickel chrome steel, it is high as compared with ordinary carbon steel; and that the elongation and contraction of area are very high indeed, indicating a very safe material for almost any construction. This material not only possesses these excellent properties, but resists dynamic stress remarkably well—in fact if the dynamic stresses are not too close to the elastic limit of the steel, it will preserve its strength and quality for an indefinite time. The following tests indicate the quality of this material as compared with carbon steel, the samples being tested under combined torsion and vibration.

Carbon steel, 15,000 vibrations; nickel steel, 34,000,000 vibrations, —not broken.

VANADIUM STEEL

10 Besides the steels already mentioned, there is another which is now attracting considerable attention; namely, that produced by adding a small quantity of vanadium to a nickel steel or chrome steel. Since vanadium has until recently been classed among the very rare elements, it may perhaps be in place to mention a few of its properties. It is prepared from the chlorid $V\,Cl_2$, which is reduced by means of a current of hydrogen gas, the chlorid being heated while the reduction is taking place. Simple as this process may seem, it is one of the most

difficult known to chemists, and it usually requires three or four days to prepare a fraction of an ounce of the metal by this process. Until quite recently this element and its compounds, owing to their rarity, were very expensive, but we are now assured by the American Vanadium Company that a sulphid of vanadium has been discovered in an immense quantity in the Andes mountains of South America, and that they are prepared to furnish the metal in the form of a ferro alloy, known as ferro-vanadium, in any quantity desired.

11 This ferro-vanadium contains about 20 per cent of the latter metal, and is readily incorporated with the iron or steel during the melting, either in the open-hearth or crucible process. Mr. J. Kent Smith, who has given the subject of vanadium steel much attention, advocates the open-hearth process as preferable to the crucible process for the making of this steel. This steel possesses most remarkable qualities, notwithstanding the small quantity of vanadium which it contains. One of these is the closeness with which its elastic limit approximates its tensile strength, and since the former quality is the one in which the greatest dependence is placed, this is a very desirable characteristic. The sharp contraction of area, also a characteristic of this steel, together with the silky fracture it usually presents, is also a strong indication of the splendid quality of this material. Moreover, the fracture is nearly always of this quality, even though the steel has been highly tempered.

12 It is a rather remarkable fact that the vanadium alone or with carbon does not give much character to the iron or steel, but when a third element is introduced, such as nickel or chromium, the characteristics of the steel are changed for the better. Whether the vanadium acts as an essential element in the composition of the steel or principally as a purifier is not fully known; it has been found, however, that a certain amount of the vanadium introduced (about $\frac{1}{4}$ per cent), must remain in the steel in order to give it its characteristic properties. Vanadium, however, has a strong affinity for nitrogen as well as for oxygen, and it may be that it acts as a purifier of the steel by combining with minute quantities of nitrogen gas, which might otherwise be occluded in the steel and thus interfere with its compactness and strength.

13 It will readily be seen that the high elastic limit, strong contraction of area and splendid silky fracture, together with the large number of vibrations which the steel endures under dynamic stress, most strongly recommend this steel as almost ideal for many parts of the motor car. The writer has made some experiments in the forging, and found that it works well under the hammer, though it must not be

allowed to become too cold or it will resist pounding to a remarkable degree. It is not readily injured under the forging hammer, provided due care is taken not to heat it too rapidly. Another valuable property of the steel is the fact that it machines more readily than nickel chrome steel—in fact, more readily than plain nickel steel.

BRONZE AND OTHER ALLOYS

14 The use of bronzes in the motor car must necessarily be restricted to parts requiring low rigidity, and usually also moderate strength. While it must be admitted that samples of bronzes can be made that approach closely to fairly good grades of steel in tensile strength, elastic limit, and contraction of area, it must also be remembered that the modulus of elasticity of iron and steel is about 28,000,000 pounds, for example, while that of bronze is only about 15,000,000 pounds. This means that a bar of bronze of a given size and form under given conditions will deflect nearly twice as much under the same load as a similar bar of iron or steel. In most parts of the car this feature is objectionable, since changes of alignment are likely to occur, unless the parts which are made of this material are especially well designed.

15 Notwithstanding the above objection the readiness with which bronze lends itself to the production of castings of various parts, and its freedom from crystallization under dynamic stress has led to its introduction into many of the minor parts of the motorcar, such as small hand levers, carbureters, tubing, crank cases, gear cases, etc. In general, it may be said that it is suitable for the small levers such as those used for controlling the sparking mechanism, carbureter, etc. Another use for this metal is in bearings, although these require a decidedly different composition from that used for levers, crank cases, and like parts.

16 The parts requiring strength are usually made from nickel bronze, phosphor bronze, manganese bronze, or aluminum bronze, while the bearing bronzes are composed usually of lead, tin, and copper in various proportions. Under this latter head come also the so called babbit metals which vary greatly in their composition, some of them being composed of lead, copper, tin, and antimony; others of lead, tin, zinc, and antimony, and still others of lead, tin, and antimony. It is not the purpose of the writer to discuss the merits of these various bearing metals, since a number of very good ones can be readily obtained on the market.

17 Beside the above alloys, pure copper is used to a considerable extent in the construction of radiators, gasolene tanks, etc. It is well

adapted for the construction of radiators, since it can easily be soldered; is one of the best conductors of heat, and is readily formed into almost any shape on account of its malleability, ductility, and comparative softness.

ALUMINUM

18 Aluminum is now used very largely in automobile construction, and it is a significant fact that it was first introduced into the automobile in America, though the French used it quite early to some extent for a few minor parts of their machines. Pure aluminum is used only for a few special purposes, and even then to a limited extent—most notably for tubing and radiators. It is quite well adapted for the latter purposes in many respects, but the comparative difficulty experienced in soldering it is a drawback. On the other hand, when alloyed with copper or some other metal giving it increased hardness and elasticity, it is well adapted for various purposes such as seats, gear cases, crank cases, dashes, and various other parts of the car. Its extreme lightness, together with the ease with which it may be machined and the facility with which it may be cast, renders it very useful for many parts of the machine.

19 An alloy of zinc and aluminum seems to have considerable rigidity and elasticity, as well as quite high tensile strength. It is also cheaper than the aluminum copper alloy, but experiments made by the writer indicate that this alloy is not safe if subjected to repeated vibrations, since it seems to fatigue quite rapidly and sooner or later breaks off short. For example, a ½-inch square bar made of an alloy of aluminum and zinc withstood only about 15,000 vibrations before breaking, while an alloy of copper and aluminum withstood 1,600,000 vibrations of the same amplitude and frequency without breaking or showing any signs of injury except a very slight set. Aluminum also forms a very light alloy with magnesium, which, however, is too expensive for ordinary use and is somewhat difficult to handle in quantity. A number of other alloys of aluminum have been prepared, and to some extent used in automobile construction—the most notable perhaps of which is an alloy of tungsten and aluminum, which has been used to a considerable extent abroad, but is not used in American cars so far as the writer is aware.

RECAPITULATION

20 From the foregoing it may be said that the following substances have proved suitable for the various parts of the automobile:

a For rear live axles, nickel steel containing from 4 per cent to 5 per cent nickel and less than 0.3 per cent carbon.

b For front axles, steering knuckles, propeller shafts, etc., vanadium steel.

c For sliding gears, nickel chrome steel hardened throughout, or mild nickel steel case hardened.

d For crank shafts, nickel steel or vanadium steel.

e For frames, low carbon open-hearth steel, mild nickel steel or nickel chrome steel.

f For nearly all other parts of the car, such as hand levers, tubing, etc., a good open-hearth steel of comparatively low carbon—say 0.4 per cent or under—is of suitable quality, since there is no advantage gained by using high class steels for these purposes for the reason that the rigidity of these parts is of prime importance, and in order to make them sufficiently rigid, they must be made much more than sufficiently strong; therefore, since all steels are practically equal in rigidity, one steel is, broadly speaking, as good as another for these parts.

21 The use of bronze should be restricted largely to minor parts; the reducing gear wheels, small levers, etc., can be made of phosphor bronze, while the bearings should be made of some good composition bronze—an alloy of copper, lead, tin and zinc answers well for this purpose, but the main bearings for the engine, such as the crankshaft, crank pins, etc., should be made of a special bearing metal, which is very firm and at the same time will not injure the crankshaft in case the lubrication becomes deficient. The crank case of the motor, the gear case, and other similar parts may well be made of aluminum, since it is light, strong, and easily cast into the proper shape. Steel would answer for the above parts if it could be conveniently worked into the proper form.

22 It will be noticed from the foregoing that the most progressive automobile builders have spared neither pains nor expense in obtaining the very best materials that can be produced, because in order to obtain the highest results in automobile construction, it is necessary that material of superior quality shall be used for certain parts of the machine. Perhaps there is no form of construction that taxes the ingenuity of its builders more severely than the building of a good automobile. Those who are versed in mechanical matters and who know the sizes of parts generally used for heavy stress, often marvel at the strength and endurance of the modern automobile. Factors of safety must be reduced to the minimum in nearly every part of the

machine or excessive weight is sure to occur. Many high class machines weigh less than 70 pounds to the horse power, passengers included. Of course it is not expected that the motor shall be used constantly at anything near its maximum horse power— $\frac{1}{10}$ of its brake horse power is enough for almost any automobile motor when in daily use; high power is simply intended to meet emergencies, but the material throughout the machine must be strong enough to withstand any stress momentarily applied.

23 The following table gives approximately the strength of various materials used in automobile construction:

TABLE 2 STRENGTH OF AUTOMOBILE MATERIALS

	Modulus of rigidity	Elastic limit	Tensile strength
Aluminum alloys	8 to 11 million	10M to 15M	20M to 30M
Phosphor bronze	12 to 14 million	20,000	30,000
Manganese bronze	15 million	35,000	50,000
Aluminum bronze	15 million	50,000	75,000
Wrought iron	28 million	30,000	40,000
Mild open hearth steel	28 million	40,000	60,000
Tool steel	29 million	80,000	110,000
Nickel steel	28 million	80,000	110,000
Nickel chrome steel	30 million	160,000	180,000
Vanadium steel treated	30 million	220,000	228,000

All of the above materials stand well under dynamic stress with the exception of the tool steel, which should not be used for this purpose.

No. 1149

EUROPEAN RAILWAY MOTOR CARS

By B. D. GRAY, PROVIDENCE, R. I.

Non Member

As a result of continued and consistent experimentation, covering a period of four years or more, conducted by numerous English and Continental railways, the self propelled railway car has been brought to such a degree of refinement that it has become an important and established factor in the transportation of passengers and light goods traffic. While its inception dates back many years—experiments along this line having been made as early as 1873—the successful development of the self contained car is quite recent. Owing partly to the crudity of early designs, but largely to under-estimation of its possibilities and lack of appreciation of the necessity for frequent and rapid train service, and because the demands of the traveling public were not nearly so exacting as at present, the early experiments were probably premature; but the phenomenal growth of our large cities, the grouping of commercial interests, and the ever present desire for home comforts, have removed residence districts from business centers, and brought about the necessity for efficient suburban and interurban transportation facilities. Greater demands upon business men's time have likewise contributed to the necessity for rapid transit. The influence of metropolitan activity is felt in the smaller cities and provincial towns, and extends even to the most remote country districts.

2 In the United States, electricity has been widely adopted as a motive power and has met with marked success the demands for quick and reliable service. Electrification of existing steam roads and the building of new electric lines have not been taken up as generally in Europe, and it is therefore only natural that the engineers of those railways should look for the solution of the frequent service problem by a vehicle which might be adapted to existing conditions with no expenditure for equipment other than that for the vehicle

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itself. This condition of affairs probably influenced recent builders of motor cars in selecting steam as a motive power, although its predominance at the present time is due chiefly to its low fuel cost and great flexibility.

3 Numerous English and Continental railway companies have permanently established motor car service on their lines in different localities with marked success. The practicability of the self contained car for certain kinds of service can no longer be doubted, nor is its field so limited as might be generally supposed. One may see such cars operating on unimportant branch lines as feeders to trunk line trains; on main lines through thickly populated districts carrying passengers and luggage to and from the more important towns served by express trains; on suburban lines in competition with both trolley cars and steam trains; on an entire railway system where there is no other means of transportation except for heavy freight.

4 Its adoption permits better service with greater frequency at lower cost of operation than is possible with the ordinary steam train, comprising a locomotive and one or more passenger coaches or combination cars, the lower operating cost being due chiefly to decreased fuel consumption and a reduction in the train crew. Motor car equipment is cheaper to install than ordinary train equipment, therefore fixed charges on the investment are correspondingly less. Maintenance charges on rolling stock are about the same in both cases, but track maintenance is less where motor cars are used because of decreased weight.

5 As compared with electric railways for interurban service where current is supplied from a central station, the relative economy depends chiefly upon the frequency of the service. Taking into account the cost of equipment, installation, operation, current losses, etc., it is fair to assume that where cars are to be run at 30 minute intervals or less, the electric railway is the more economical, but where car or train intervals are greater than 30 minutes, the balance is in favor of the self propelled car.

6 The following list comprises the principal railways operating motor cars, the motive power of these cars, and type:

RAILWAY	MOTIVE POWER	SYSTEM
	ENGLAND	
Great Western	Steam	Great Western
Taff Vale	Steam	Taff Vale
London & South Western	Steam	L. & S. W.
Lancashire & Yorkshire	Steam	L. & Y.
North Eastern	Petrol-Electric	N. E.

RAILWAY	MOTIVE POWER	SYSTEM
	FRANCE	
Paris, Lyon & Mediterranean	Steam	Purrey
Paris, Lyon & Mediterranean	Steam	Serpollet
Paris, Orleans	Steam	Purrey
French State	Steam	Purrey
	BELGIUM	
Belgium State	Steam	Belgium State
	SWITZERLAND	
Swiss Federal	Steam	Serpollet
Swiss Federal	Gasolene	Ger. Daimler
	AUSTRIA	
Austrian State	Steam	Komarek
	HUNGARY	
Hungarian State	Steam	Gans
Arad and Csanadar	Gasolene	Ger. Daimler
Arad and Csanadar	Steam	Gans
Arad and Csanadar	Gasolene-Electric	Weitzer

LONDON & SOUTHWESTERN RAILWAY

7 The London & Southwestern Railway was one of the pioneers in the movement for self-contained cars, and in 1903 placed a steam car on their line between Fratton and South Sea. This car was equipped with small cyclinders and vertical boiler, and while not capable of high speed or quick acceleration, the results obtained were satisfactory from the standpoint of economy of operation, and probably encouraged, more than anything else, other railways to take up this problem. This car has a total length of 50 feet, and seats 40 passengers. The cylinders are inclined, driving the leading pair of wheels only.

GREAT WESTERN RAILWAY

8 One of the most satisfactory cars in operation abroad at the present time is the one developed by Mr. Churchward, chief engineer of the Great Western Railway of England. In the neighborhood of sixty of these cars are in service on various parts of the Great Western system, and others are in course of construction. They combine, to a remarkable degree, many of those qualities essential to success;

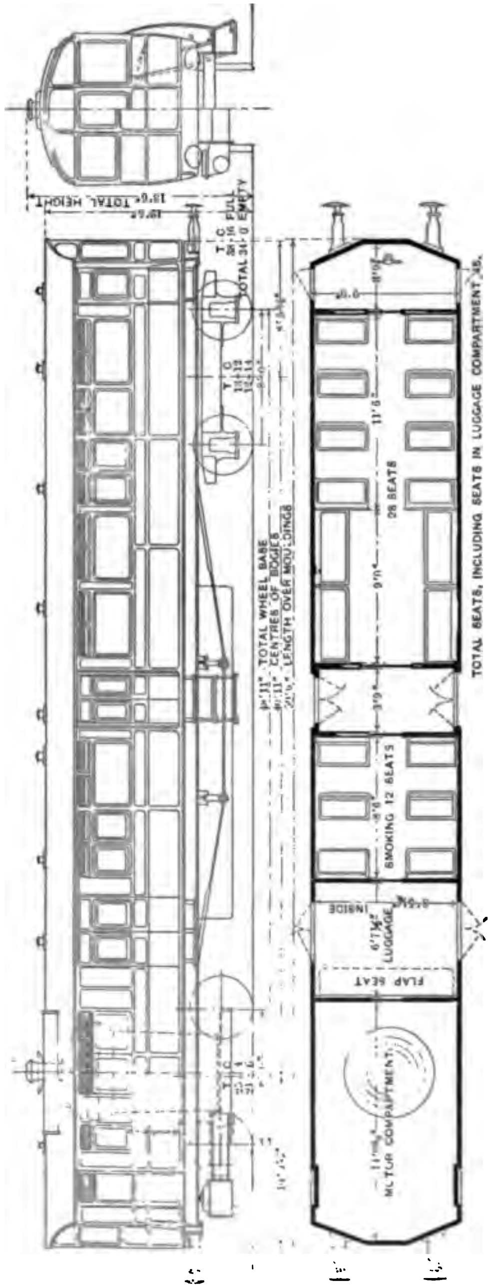

FIG. 1 TYPE OF MOTOR CAR COSTING ABOUT $9000

large seating capacity with only moderate weight, flexibility of control, reasonable speed and acceleration, reliability, low maintenance and fair operating costs.

9 The boiler is of the vertical, fire tube type, with no superheater, supported directly on the frame of the power truck, and serving as a center pin by transmitting the driving effort to the sills of the car through flat springs. It is enclosed within a compartment of the car body, about 14 feet long, which contains the coal bunkers, operating levers, etc. As the car is arranged to run in both directions and controlled from both ends a stoker is employed in addition to the driver. Aside from attending to the fire it is his duty to regulate the cut off when the driver is at the other end of the car, as only brake and throttle connections are provided there.

10 The motor consists of two single expansion cylinders 12 in. by 16 in. coupled direct to the rear driving wheels, which in turn are coupled to the front drivers. Walschaert valve gear is used.

11 Air brakes are provided, the usual form of steam actuated automatic pump being used to supply the air. The water supply is carried in tanks hung beneath the car body midway between the trucks.

12 As an indication of the reliability and commercial success of these cars, the following instance of service conditions may be cited; Two motor cars and four or five trailers are used on the main line of the Great Western between Chalford and Stonehouse, a distance of about seven miles. The railway at this point runs through what is known as the Stroud Valley, a thickly populated section comprising in all about 40,000 inhabitants in the nearby towns and outlying districts. The motor car schedule provides, on an average, fourteen round trips per day (a total of about 200 miles) so arranged as to run these cars between through trains, both passenger and freight. There are ten stops in the seven miles, and the running time each way is from 23 to 25 minutes.

13 Stroud, the most important town in this section, is located about midway of the run, and is served by express trains. The frequent motor car service provides an attractive means of reaching express trains in addition to local transit, and has resulted in a material increase in traffic in that section. Ordinarily, one motor car suffices, but on Saturdays, Sundays, and holidays, when traffic necessitates, both cars are used, and frequently with one or two trailers.

14 Fares range from 2 to 8 cents, depending upon the distance, the average weekly receipts being about $300.

15 These cars are capable of a maximum speed of 55 miles an

hour, although the average running speed is 30 to 35 miles an hour. Their maximum acceleration is about one mile per hour per second.

16 The original cost of the type of motor car shown on Fig. 1 is about $9000, and the cost of operation, aside from the guard's pay, is 13 cents per car or train mile, including trailers, for the service above referred to, the coal consumption being about 20 pounds per train mile. The wages paid to men operating these cars are about as follows: guard, 6 shillings per day; driver, 7 shillings per day; stoker, 3 shillings 6 pence per day.

17 The Great Western Railway Co. are now building a series of trains for service similar to that described above, consisting of a small locomotive and four cars, two at each end with the locomotive in the middle. In this case, the stoker only remains on the locomotive, the driver controlling the train from either end.

TAFF VALE RAILWAY

18 The Taff Vale Railway has built a number of cars for their own use and for other railways, the designs varying slightly to suit the conditions of the different roads. Those used by the Taff Vale Railway are similar to the Great Western car in most respects, the chief difference being in the construction of the boiler, which is of rather peculiar design. It is of the fire tube type, and consists practically of two horizontal barrels placed on either side of a central furnace, the hot gases passing horizontally through the fire tubes to smoke boxes at the outer ends, and from there through flues to a central stack. The boiler is placed transversely with reference to the car body, and rests directly upon the truck frame just aft of the forward axle, which is the driving axle. The forward end of the car body is pivoted on the power truck, but does not include a compartment for boiler, etc., as in the case of the Great Western.

19 The power truck is self contained, and a cab is provided for the driver similar to that of a small locomotive. The cylinders are placed outside, and the valves operated by an ordinary link motion with rocking shaft. The car is heated by steam from the engine with warmers of acetate of soda, and light is furnished by the Pintsch system of oil gas. Both hand and vacuum brakes are provided. The conductor can communicate with the motorman by means of an electric bell, and also shut off steam and sound the whistle. This car is capable of running 35 miles per hour on the level, and will ascend a 2½ per cent grade at 20 miles per hour. It may be operated from either end, and all operations, except starting, can be performed from the guard's

compartment. It is claimed that it is possible to remove the engine from the car body in 20 minutes.

Latest type of Taff Vale car:

Over all length, about 70 feet
Seating capacity, 43
Total weight, 42 tons
Weight on power truck, 30 tons
Cylinders, bore $10\frac{1}{2}$ inches; stroke, 14 inches
Tòtal heating surface of boiler, 465 square feet
Grate area, 10 square feet
Capacity of water tank, 550 gallons
Steam pressure, 180 pounds
Tractive force, 5292 pounds
Boiler has 232 $1\frac{5}{8}$-inch tubes

LANCASHIRE & YORKSHIRE RAILWAY

20 The Lancashire & Yorkshire car is similar to the Taff Vale car in this respect, that the forward end is pivoted on the power truck, although it is necessary for the underframing to project some distance forward of the car body to reach the pivotal point, owing to the fact that the driver's cab extends somewhat to the rear of the rear axle of the power truck.

21 The boiler is of the usual locomotive type with horizontal fire tubes. This engine is practically a small locomotive with drivers coupled.

Heating surface:

199 fire tubes $1\frac{3}{4}$ inch outside diam., area	455 square feet
Fire box area	54 square feet
Total	509 square feet
Grate area	9.4 square feet
Water capacity	550 gallons
Boiler pressure	180 pounds
Coal	1 ton

Two cylinders, bore 12 inches, stroke 16 inches

NORTH-EASTERN RAILWAY

22 About three years ago, the North-Eastern Railway of England put into service two "petrol-electric" cars on a short line running out from Scarborough. Owing to the fact that traffic on this line is heavy during the summer season only, these cars are laid up during the winter, and have therefore not been in continuous service. One gallon of gasolene to $3\frac{1}{2}$ car miles is claimed for them, but the maintenance charges must necessarily be high.

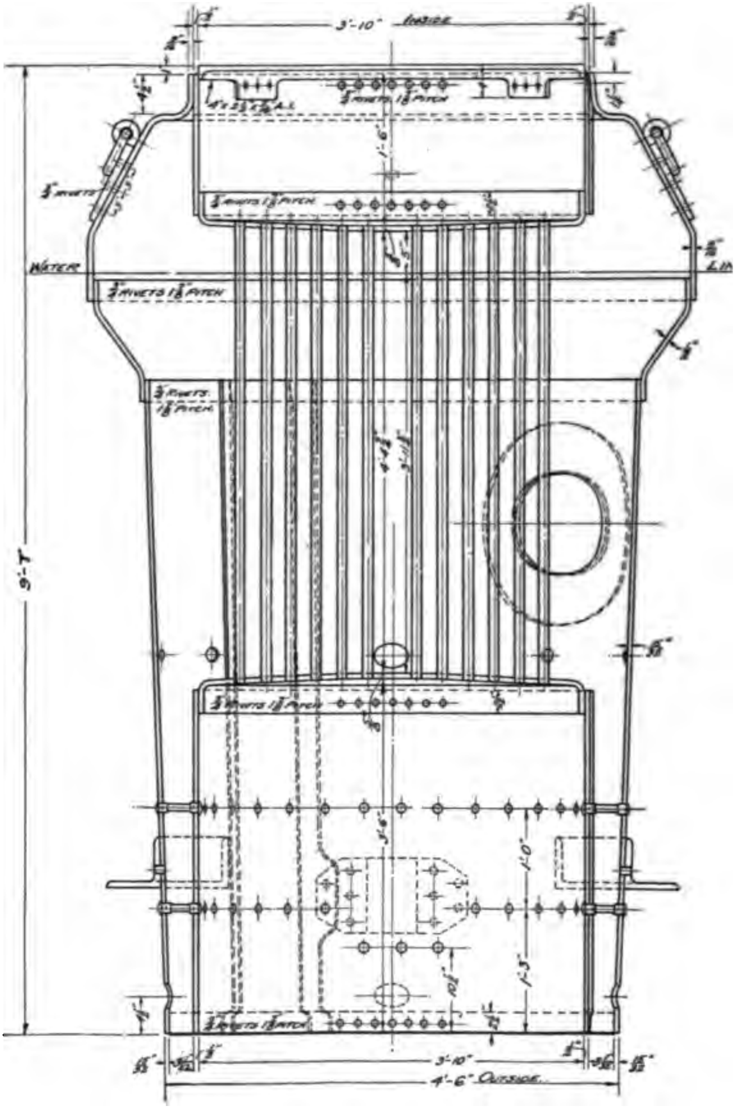

FIG. 2 GREAT WESTERN BOILER

Heating surface:

420—1¼ in. fire tubes—area 613 sq. ft.

Firebox. 46 sq. ft.

Total. 659 sq. ft.

Grate area, 11.54 sq. ft.

Steam pressure, 160 lbs.

23 The power plant consists of a 4-cylinder horizontal opposed Wolsley engine, 8½ in. by 10 in., 85 b. h. p. at 420 r. p. m., direct connected to a compound wound, separately excited generator, of 55 kilowatt capacity, which furnishes current to two 50 horse power electric motors, of the ordinary railway type, on the leading truck.

24 The exciter of 3.75 kilowatt capacity is mounted above the main generator, and driven by a belt from the flywheel of the engine. In addition to exciting the fields of the generator, it is used to charge a storage battery which supplies current for lighting the car, starting the generator and gasolene engine, and for a small automatic compressor motor, which supplies air for the whistle. The battery and the compressor outfit are suspended beneath the car body. The engine and main generator are very cumbersome and heavy, and occupy practically one-third of the total length of the car. The total weight, including 60 gallons of gasolene and about 100 gallons of cooling water, is 35 tons, of which 22 tons are carried on the power truck.

25 Radiating pipes located above the engine room, and supplied with air by a horizontal fan, in addition to that due to the motion of the car, serve to cool the jacket water. For extremely warm weather, an additional coil extending along the roof is provided and pipes are also arranged inside the car to be used for heating in cold weather. Electric brakes are used, the current being supplied by the motors acting as generators.

26 Controlling apparatus is provided at both ends of the car, and only two men are required to operate—motorman and guard. The wages paid are about 7 and 6 shillings per day, respectively.

27 The complication of this system, the multiplicity of parts, and the excessive weight give a rather unfavorable impression. The combined efficiencies of the generator and motors must of necessity be low, and their use can only be reconciled with the extreme flexibility of transmission necessitated by a large unwieldly gasolene motor. As this particular type of car has not been perpetuated by the orginal builders and users, it may be safe to assume that itis not entirely satisfactory. It is the author's opinion that its indifferent success isdue to the enormous size and weight of the power plant throughout, as a number of cars embodying practically the same principles, but of much lighter construction, have been in successful operation in Hungary during the past three years.

FRENCH RAILWAYS

28 Numerous experiments have been made on the different rench railways, including the Paris-Orleans; Paris, Lyons & Medi

terranean; Northern; Western and the State railways, with various types of cars, but the most successful at the present time, and the one being almost universally adopted, is that of Purrey, of Bordeaux and although differing in minor structural details, the power plants of the Purrey cars as built by the different railways are practically the same. There is also a slight variation in the size, weight, and arrangement of cars to meet best the requirements of the different roads, but that of the Paris-Orleans Railway is fairly representative of all the cars used in France.

PURREY CAR (PARIS-ORLEANS RAILWAY)

29 The car body has a total length of about 60 feet, and seats 30 third-class passengers in three compartments, and 25 first-class passengers in 2½ compartments. In addition to this, there is a baggage compartment at the forward end 11 feet 6 inches long and extending the entire width of the car, 112 inches. The forward end is pivoted on a power truck, the rear end being carried upon a single axle. The power truck, which carries the boiler, motor, fuel, water, etc., has two axles 126 inches apart, the rear wheels only being used for driving The weight of this truck is 14½ tons, of which about 7 tons is on the rear axle. The total weight of the car complete is in the neighborhood of 35 tons.

BOILER

30 The Purrey boiler is tubular, its general construction being illustrated by Fig. 3a and 3b. Two drums are provided, the lower one of rectangular section and made of cast steel, the upper, cylindrical and of cast iron. The lower drum is divided into three compartments, two of which are provided for water, the third for superheated steam The outer and lower compartment is connected with the upper drum by two large return pipes. It is also connected with the intermediate compartment of the same drum by 41 U shaped tubes. The feed water entering the lower compartment is thus heated in passing through these tubes, which are in direct contact with the flame From this point, the water rises through a series of U shaped tubes to the upper drum, and the steam thus formed is returned from the upper drum, in which the water level is maintained at about the median line, through a number of similar tubes to the third compartment of the lower drum, from which it is taken to the motor. The steam is highly superheated in these tubes, the average temperature of superheat being from 750 to 900 deg. fahr. At first, considerable trouble was experienced with the burning out of the superheater

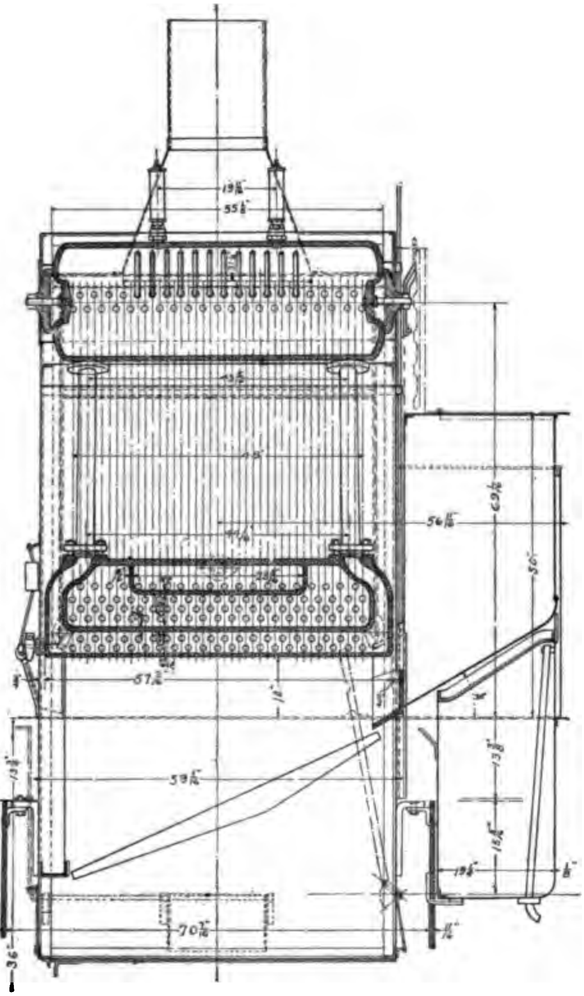

FIG. 3a PURREY BOILER

Total capacity, 118 gallons.
Steam pressure, 284 lb. per sq. in.
Number of short water tubes, 41.
Number of long water tubes, 29.
Number of superheater tubes, 12.
Inside and outside diameter of tubes, 26 by 30 mm. (1 in. by $1\frac{3}{16}$ in.)
Inside and outside diameter of lower end of superheater tubes, 22 by 30 mm. ($\frac{7}{8}$ in. by $1\frac{1}{8}$ in.)
Total heating surface 255, sq. ft.
Superheater surface, 80 sq. ft.
Grate area, 11.62 sq. ft.
Outside diameter of upper drum, 20 in.
Total length of upper drum, 56 in.

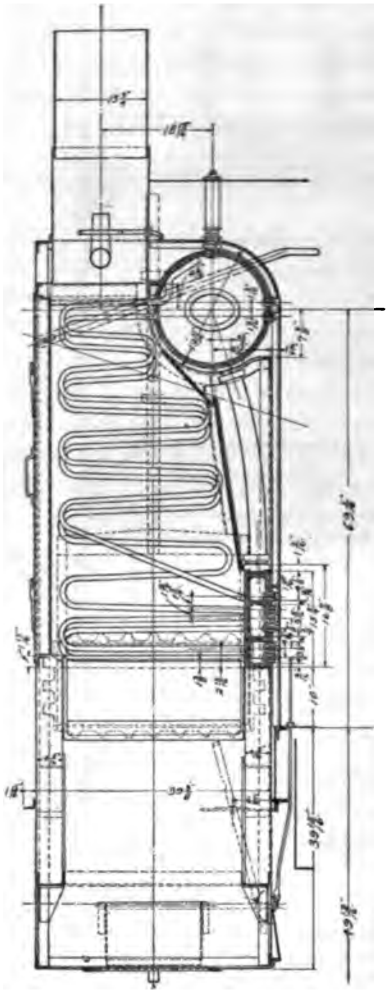

FIG. 3b PURREY BOILER

tubes in the lower coils which were in the most direct contact with the flame. This difficulty was overcome by eliminating two coils and increasing the thickness of the tubes at that point. Originally all tubes were 2 mm. thick, but those referred to were increased to 3 mm.

31 An inclined grate is provided, and the fuel (coke) feeds from the bunker attached to the side of the boiler, automatically, or practically so, the only attention necessary on the part of the driver being to regulate the supply by means of a vertical sliding door, operated by a lever, at the point where the bunker communicates with the furnace. Where price is not prohibitive, kerosene might be used to advantage, and would permit more perfect control of fire, and thus avoid burning out tubes.

32 An arrangement is provided for automatically maintaining a constant water level, consisting of a float inside the upper drum connected through a stuffing box to a valve in the steam line running to the feed pump, the idea being that as the level of the water is lowered, the steam valve opens and the pump supplies water until the level has reached that point at which the float closes the steam valve. This was found to be very unsatisfactory as the stuffing box, if made tight enough to prevent leakage, created so much friction that the apparatus would not work. It was therefore necessary to depend upon the driver to maintain a correct water level, Blake double acting feed pumps being provided for this purpose.

MOTOR

33 The motor is 4-cylinder tandem compound, high pressure $6\frac{5}{16}$ inches diameter, low pressure $8\frac{11}{16}$ inches diameter, and the stroke $8\frac{7}{8}$ inches, rated at 260 horse power at 650 revolutions per minute. A by-pass valve is provided to admit high pressure steam to the low pressure cylinders for quick acceleration and unusually heavy pulling. Ordinary D type valves are used, operated through Stephenson link motion.

34 In this design, the motor is attached horizontally to the frame of the car, and its power transmitted to the rear axle by two toothed chains of special construction, similar to the Renold and Morse silent type. All the working parts are enclosed in a dust proof case, and lubricated principally by splash. The motor is accessible through a trap door in the floor of the baggage compartment, and any ordinary adjustments can be made from this point. A door is also provided opening into the baggage compartment through which the boiler tubes may be inspected, thus rendering the most delicate parts of the

mechanism readily accessible. Should it be necessary to overhaul the boiler or motor, the power truck may be removed from the body of the car in 20 minutes and another substituted in its place. Westinghouse air brakes and hand brakes are used. Steam whistle is provided.

35 The Paris-Orleans road have 10 cars and 12 power trucks, and have been able to keep the 10 cars in service practically all the time by having the two extra trucks in reserve. Replacing boiler tubes is a comparatively simple matter. By removing plugs in the two drums on the opposite sides from where the tubes enter, the tubes are accessible either for driving out or expanding.

36 As a rule, one or two trailers are attached to these motor cars, the average weight of the train being 50 tons. The fuel consumption for such a train is about 21 pounds of coke per mile.

37 This car is arranged to run in one direction only, except for backing up, and the crew consists of only the driver and one man in the baggage compartment, tickets being taken at the stations by inspectors. It is geared rather high, and is capable of running at a speed of about fifty-six miles per hour. Its acceleration, however, is not so good as that of the Great Western car.

38 The Orleans road has instituted a motor car service between Bourges and Saincaize, a distance of 59 kilometers (37 miles), the run being made in 70 minutes, including eight stops. Sufficient fuel and water capacity are provided for a run of 50 kilometers. The cost of operation per train mile is about 7 cents, itemized as follows, train weighing approximately 50 tons:

Fuel (coke)	$0.0355
Kindling wood	0.0013
Oil	0.0022
Water	0.0005
Repairs	0.004
Driver's wages	0.0264
Total	0.0699

39 This of course does not include the wages of the guard, nor any of the overhead expenses. It is probable, however, that the cost of operation of this car is somewhat less than that of the Great Western.

40 The Purrey system has been used for a number of years on different tramway lines in the city of Paris, but for this service it has been found that the single expansion engine gives better results than the compound, and also that there is no advantage in having a vari-

able cut off, owing to the frequency of the stops, the speed of the motor being controlled entirely by the throttle valve.

ARAD CSANADAR RAILWAY OF HUNGARY

41 One of the most interesting examples of successful operation of railway motor cars on a large scale is that of the Arad Csanadar Railway of Hungary.

42 Three years ago a Ganz steam car was put into service on this road in an experimental way, and the results were so satisfactory that the management decided to replace their locomotive and train service for passenger and light goods traffic, with the self-propelled car, and have gradually added to their motor car equipment until now they have a total of 37 cars of which 4 are Ganz steam cars 35 horse power of the de Dion system; 22 are gasolene-electric 30–35 horse power of the de Dion Bouton system, constructed by Johann Weitzer; 10 are gasolene-electric 70 horse power of the de Dion Bouton system; 1 is gasolene 40 horse power (German Daimler.)

43 The total length of this railway is about 400 kilometers, single track, running for the most part through a sparsely populated agricultural district where conditions are conducive to economical operation, as the average Hungarian peasant is not very fastidious nor exacting in the matter of luxuriously furnished cars or rapid transportation. Their cars are of very light construction, and being run at low speed, require small power plants in which the fuel consumption is comparatively low. Only the heavy freight traffic is handled by steam locomotives, and in 1906 the motor cars covered a total of about 1 000 000 miles, in most cases hauling from one to four trailers.

44 The improved service offered by the motor car has stimulated traffic in that section to such an extent, that within the past two years it has doubled. One of the most remarkable features in connection with the success of this railway is the extremely low fares, which average about ⅓ cent per mile, and yet the road pays about 8½ per cent on the investment of $6,500,000, after paying 19 per cent of the total receipts to the government as a tax. The comparative cost of operation of the different cars owned by this road are given in the following table, which represents an average for 1906. No data were obtainable on the Daimler gasolene car.

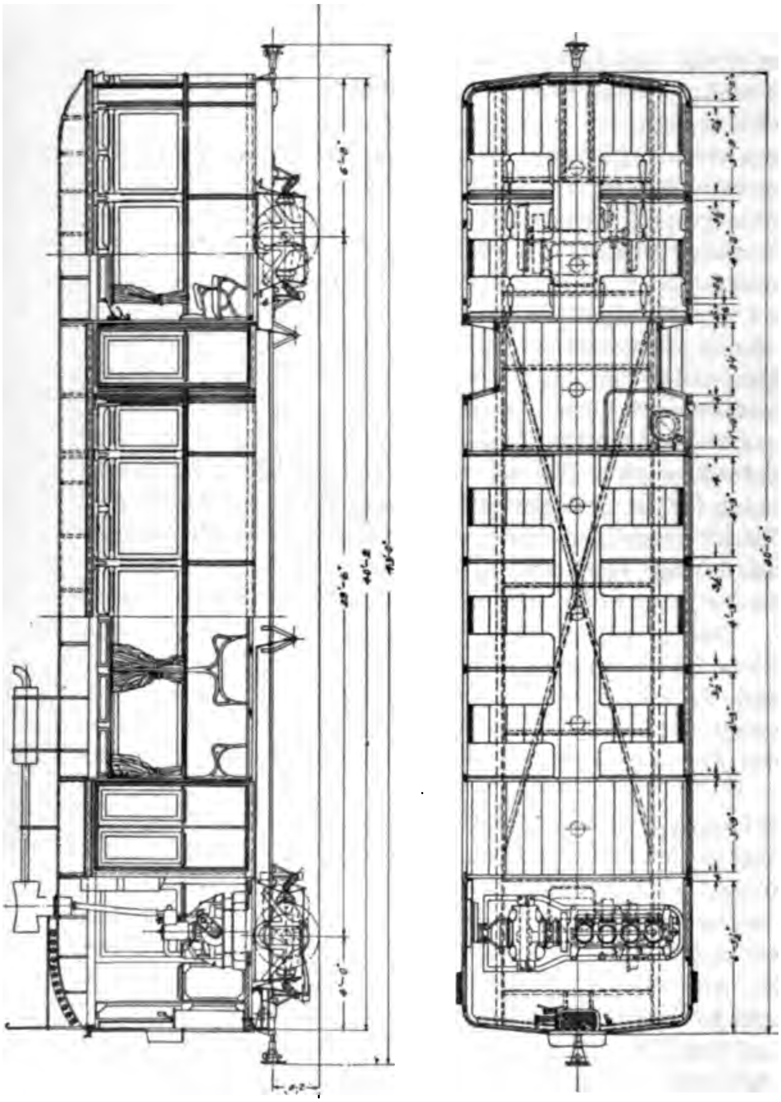

FIG. 4 ARAD CASANADAR 70 HORSE POWER CAR, GASOLENE—ELECTRIC

Over all length, including buffers, 43 ft.
Wheel base, 28 ft.
Seating capacity, first class, 12; second class, 24
Brakes, Bocker air brake and hand brake, 8 shoes.
Lighting, acetylene.
Heating, warm water.

TABLE 1 COST OF OPERATION

Type of car	Fuel per train mile	Fuel	Oil	Sundries	Labor	Total labor and material	Maintenance, labor and material	Total cost
Ganz 35 h. p.	Coke 9.6 lb.	0.034	0.0084	0.00058	0.0192	0.06218	0.0128	$0.0749
Gas.-elec. 70 h. p.	Gasolene at 10c gal. 2.11 lbs.	0.034	0.0066	0.00064	0.0144	0.05564	0.017	0.0726
Gas.-elec. 35 h. p.	Gasolene at 10c gal. 1.61 lb.	0.026	0.0028	0.00074	0.0115	0.04104	0.0163	0.0573

GASOLENE ELECTRIC CAR (WEITZER)

45 Fig. 4 illustrates the general arrangement of one of the larger gasolene electric cars used by this railway. It is equipped with a 70 horse power gasolene motor direct connected to a 45 kilowatt generator, which supplies current to two ordinary railway type motors attached to the two axles. The usual series parallel controller is provided for starting. After the car is once under way, its speed is almost entirely controlled by the throttle of the gas engine. At the right of the electric controller are two smaller levers, one of which connects with the throttle, and the other with the spark advance mechanism. In addition to these, there is a small rheostat provided within easy reach of the operator, which serves to vary the field strength of the generator, and thus gives an additional means for controlling the car during the acceleration period. Controlling apparatus is provided at only one end of the car, as it is intended to run in only one direction except for shunting. Bocker air brakes and hand brakes are provided, air being supplied by a small compressor driven from the outer end of the armature shaft. An air whistle is used. Acetylene gas is used for lighting. Coils are provided along the sides of the car body for heating, the jacket water from the motor being used for this purpose. In warm weather the jacket water is passed through a coil of tubes on the roof at the forward end where it is exposed to the air.

46 The space occupied by the power plant is considerably less in proportion to the length of the car than that of the Great Eastern, although the systems are practically identical in principle. Its acceleration is very good indeed, and its maximum speed is about 35 miles per hour without trailer, and with two trailers about 25 miles per hour. More than two trailers are never used with the 70 horse power car, as it is used for express service, but the smaller cars

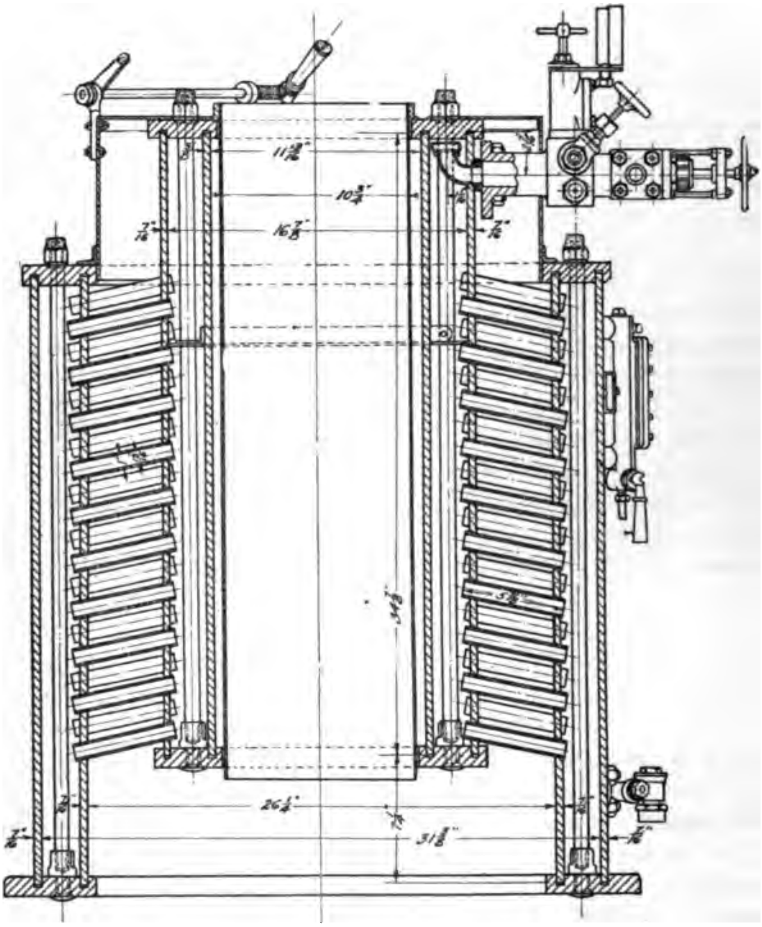

FIG. 5 35 HORSE POWER GANZ BOILER

702 Steel tubes, 25 mm. o.d., 21 mm. i. d.
Heating surfaces: Water, 62 sq. ft.; steam, 29 sq. ft.; total, 91.
Grate area, 3½ sq. feet.
Steam pressure 280 lb per sq. inch.,
Fuel, charcoal or coke.

The general arrangement is the same in all three, the boiler aced in a compartment at the forward end of the car, together l bunker, feed pumps, and controlling apparatus. The motor i horizontally on the leading truck, and drives the rear axle spur gears. It is supported in the usual electric railway tyle, one end being swiveled about the axle, and the other ed elastically from the truck frame. Control is provided at only , and only one man is required to operate the car. The 35 horse ar has a seating capacity of 22 first-class and 12 second class ers. Its over all length is about 35 feet. A speed of 35 miles r is claimed for this car with a fuel consumption of 5.3 to 7.2 of coke per mile. The same consumption is claimed with weighing from 35 to 40 tons at a speed of 12½ miles per hour. manufactured by this company are fitted with both hand brakes, Bocker and Westinghouse being used. They are eated and provided with steam whistles.

35 H. P. BOILER

The Ganz or de Dion boiler consists of four concentric cylinders aders which are held in place by bolts, forming two annular paces joined together by means of slightly inclined steel water 5 mm. outside diameter and 2 mm. thick. Within the inner is another cylinder of slightly smaller diameter through he fuel is fed to the grate below, the flame and hot gases around the water tubes to the chimney. It is claimed that oilers are very easy to dissemble and clean because of the and $6\frac{11}{16}$ inches and common stroke of $4\frac{3}{4}$ inches. Two steam operat feed pumps are provided, one being held in reserve.

50 The 80 horse power car has a total length of 46 feet, seats passengers, weighs 23 tons, and is capable of climbing a 1.6 per ce grade, with two trailers weighing 12 tons each, at a speed of 25 mil per hour. One peculiar feature of the Ganz system is the double ge reduction between the motor and the axle. Two spur gears a mounted loose on the crank shaft between the two cranks and meshi with gears keyed to the axle. A jaw clutch positively driven is pr vided between the driving gears, and so arranged as to engage eith one or the other when moved along the shaft. The ratio of reducti is about 2 to 1. As a rule, the low gear is used when the trailers a attached and for heavy grades.

51 Ganz cars are used rather extensively in central Europe, though in certain localities their boilers have not been entirely sati factory because of the frequent cleaning necessary, due chiefly impure water. Both steam and water space are somewhat limit and rather close attention on the part of the operator is required keep the water level at the correct point.

52 The Hungarian State railways tried the Ganz car, but th experience was not entirely satisfactory for the reason that the qu ity of water available necessitated frequent cleaning of the boiler.

SERPOLLET CAR

53 The Serpollet system differs from the Purrey and Ganz typ chiefly in that the boiler is of the flash type, and kerosene is general used as fuel. A very high degree of superheat is obtained, reachi even 1200 deg. fahr. which, together with the incrustation attendi the use of more or less impure water is conducive to the burning tubes. The experience of the Paris, Lyons & Mediterranean Railw with this type of car has been rather unsatisfactory, because of tu troubles, and the Purrey car is now being adopted in its place.

KOMAREK CAR

54 The Komarek car, manufactured by F. X. Komarek, Vienn and used to some extent by the Austrian State railway and several its branches, is one of the most rational in design of all in use abroa Its builders may have erred slightly on the side of weight, but it show remarkable economy and unusual freedom from repairs and troubl

of all kinds. Although built in several sizes and many forms, the following type may be considered as representative:

Car body, total length, 51 feet
Seating capacity, 35
Baggage room, 44 inches by 96 inches
Length of boiler and fuel compartment, 10 feet
Weight empty, 20 tons
Coal capacity, 1100 pounds
Water capacity, 420 gallons
Motor, 2 cylinder cross compound, outside cylinders
Cylinder diameters 10 inches and 15 inches. Stroke, 16 inches

55 Steam feed pumps of standard pattern are used, and a locomotive air pump is provided for supplying the brakes. Hand brakes are supplied as well. The cars are steam heated and lighted with acetylene. A steam whistle is provided. This car is capable of running at a speed of 25 miles per hour on a level while hauling trailers comprising a total of 50 tons. The operating cost is said to be about 5 cents per train mile, exclusive of the guard's pay, with coal costing $3.25 per ton.

COST OF OPERATION PER MILE OF KOMAREK TRAIN OF 50 TONS

Coal	$0.0253
Oil	0.0014
Maintenance:	
Labor	0.0046
Material	0.0011
Driver	0.016
Total	0.0484

56 In general, the arrangement of the four axle car is similar to the Purrey with the forward end of the body supported on the power truck. Other types with two and three axles have the boiler in a compartment at the forward end of the car body, supported by the main body frame. The motor is practically a small cross compound locomotive with outside cylinders, driving on one pair of wheels only. A vertical water tube boiler of special construction, shown in Fig. 6, is used. To provide for expansion, the inner shell is corrugated, and the tubes are accessible for cleaning and renewal through plugs and manholes in the outer shell. A superheater coil is placed in the upper part of the furnace, and heated by the exhaust gases, the degree of superheat averaging about 300 deg. fahr. This car is arranged to run in both directions, and when running backward, the guard remains on the rear platform and signals the driver at the other end by

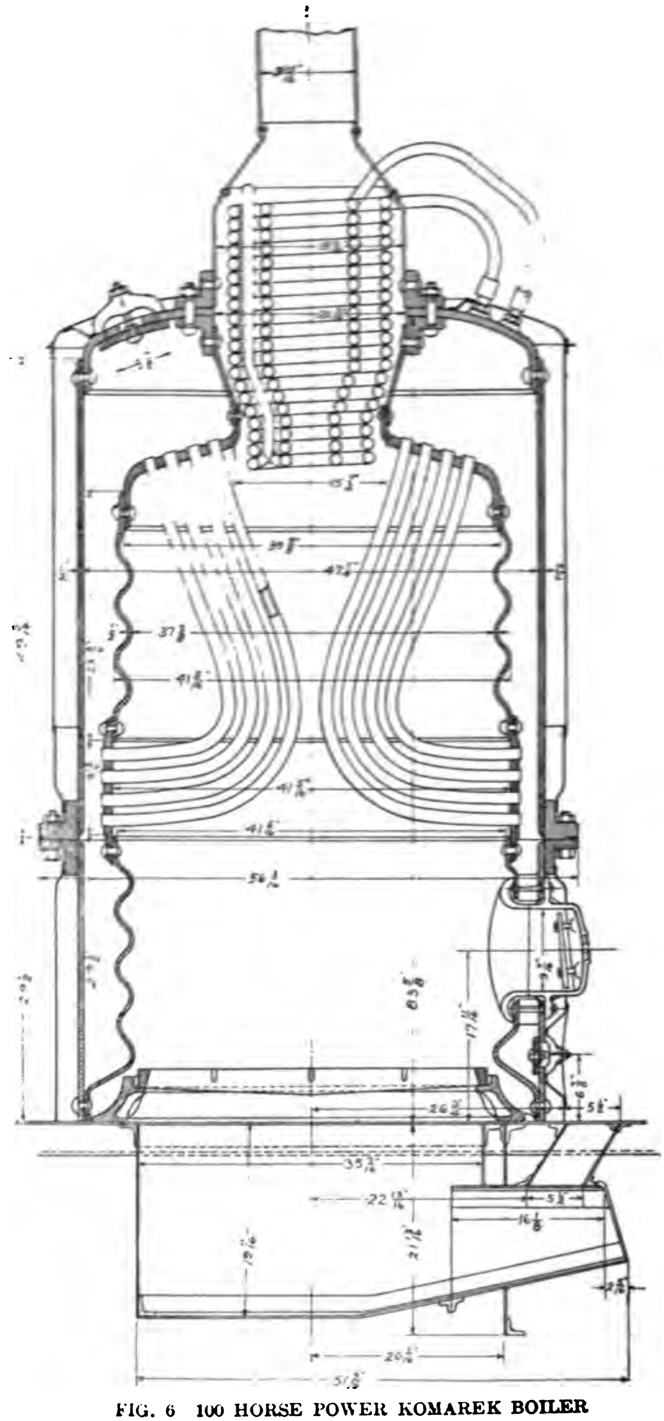

FIG. 6 100 HORSE POWER KOMAREK BOILER

Heating surface, 215 sq. ft.
Superheater surface, 32 sq. ft.
Total heating surface, 247 sq. ft.
Grate area, 7 sq. ft.
Steam pressure, 210 lb.

means of a modified system of ship signals. Air and hand brake control, and also means for closing the throttle, are provided on the rear platform so that the guard may stop the car independently of the driver.

GERMAN DAIMLER GASOLENE CAR

57 This type of car has been used in considerable quantities on some of the smaller German railways, notably the Württemberg State Railway and on the Swiss Federal Railway. It is a comparatively small car having a total length of 33 feet with a seating capacity of 36. It is equipped with a 30 horse power Daimler four cylinder (5¼ in. by 6¾ in.) engine of the heavy slow speed type, its normal speed being in the neighborhood of 550 revolutions per minute. The motor is located practically in the middle of the car, projecting upward through the floor to a considerable height, and enclosed by a wooden box. It is rigidly attached to a sub-frame, on which the car body is supported by eight elliptic springs, the sub-frame being carried rigidly on the two axles. Power is transmitted from the motor through a leather faced cone friction clutch, and through a sliding gear transmission, arranged to give four speeds and reverse, to one of the axles. Control levers are provided at either end of the car, by means of which the speed of the motor may be controlled, gear changes made, and also the direction of motion reversed. When the driver leaves one platform to go to the other, the gear levers are locked in a neutral position. Their connections to the gear case then serve as fulcrums for the operating levers and their connections at the other end of the car. The transmission is extremely heavy and the gears somewhat difficult to shift. They are not entirely protected from dust and therefore subject to rapid wear. The cone clutch requires considerable attention to secure smooth operation. If neglected, it takes hold with such brusqueness that jerking of the car results, to the extreme discomfort of the passengers. One of these cars has been in service on the Arad Csanadar Railway but has been practically abandoned because of the clutch and gear troubles.

ENGLISH DAIMLER CAR

58 Several years ago the Daimler Motor Company, of Coventry, England, built a number of small railway cars of the straight gasolene type, equipped with two 30 horse power motors carried on a sub-frame between the axles. They were placed at diagonally opposite corners of the frame, and a sliding gear transmission provided, cen-

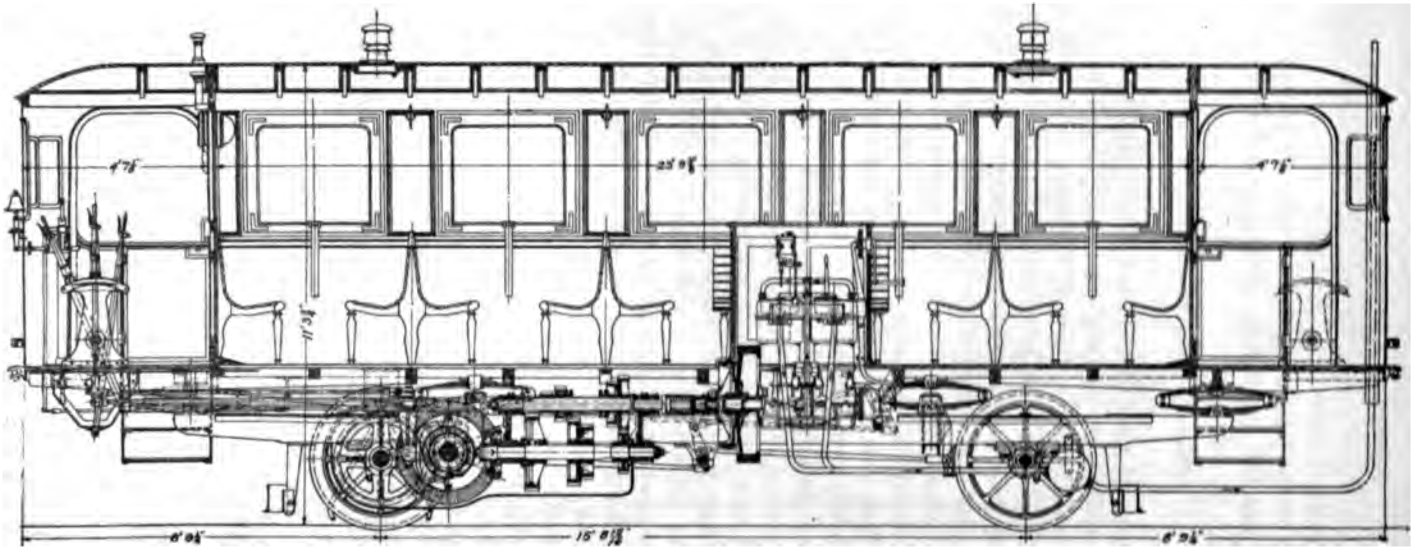

FIG. 7 GERMAN DAIMLER GASOLENE CAR

trally located and so arranged that either or both motors could drive through it, and thence through bevel gearing to the two axles. These cars have not been satisfactory because of clutch and gear troubles, and because they were rather expensive to operate, the fuel cost being high.

59 The usual friction clutches interposed between the motors and transmission permitted the use of either one of the motors independently of the other, a feature which may possess merit in minimizing fuel consumption, and in being able to proceed with one motor if the other for any reason becomes inoperative.

60 Two axle cars, such as the German and English Daimler, are not applicable to all kinds of service because of the long wheel base, which is 15 feet 9 inches in the case of the former, and 15 feet in the latter.

CONCLUSION

61 The author's impressions of the railway motor car situation abroad, gained from personal observation of the leading types herein described in operation, and from personal interviews with railway officials and others more or less directly interested, may be summed up as follows:

62 The field of the railway motor car is very broad indeed. It has always demonstrated its superiority over the ordinary steam train, in making possible more frequent service at lower operating cost, as a feeder to express trains, on branch and main lines, in either very thickly or very sparsely populated districts. It has successfuly competed with electric cars of both trolley and storage battery types, in suburban and interurban service. In the case of the Arad Csanadar Railway, it has replaced steam trains on the entire system except for heavy freight. Further refinement which will extend its field of usefulness is possible and may be expected.

63 Steam as a motive power in cars of 80 horse power or over possesses the greatest number of advantages, among which may be named flexibility, reliability and economical operation. First cost is also in favor of the steam car, and likewise to a slight extent maintenance charges.

64 For cars of less than 80 horse power the internal combustion motor shows lower fuel cost than the steam car of like power.

65 Present well known forms of gear transmission with friction clutches which are entirely successful on gasolene automobiles are not suitable for heavy cars because of their inelasticity and the enormous difference in inertia of weights dealt with.

66 Electric transmission possesses the required flexibility and seems best adapted for the purpose.

TABLE 2

BOILER DATA OF PRINCIPAL TYPES OF RAILWAY MOTOR CARS

Name or make	Type	Rated h.p.	Heating surface	Superheat surface	Total	Grate area	Ratio of grate area to total heat surface	Degree of superheat	Steam pressure
Ganz	Vertical-short inclined water tubes..........	35	91		91	3½	1 to 25.0		280
Komarek	Vertical-bent water tubes...............	100	215	32	247	7.0	1 to 35.3	600 F.	210
Great Western	Vertical-vertical fire tubes...............	250	660		660	11.5	1 to 57.4		160
Taff Vale	Horizontal-horizontal fire tubes...........	200	465		465	10.0	1 to 46.5		180
Purrey	Vertical-bent water tubes...............	200	255	80	335	11.6	1 to 29.0	900 F.	284
Lanc. & Yorkshire	Horizontal locomotive type................	250	509		509	9.4	1 to 54		180

TABLE 3 COST OF OPERATION OF FOREIGN CARS

Ry. using car	Type	H. p. weight of train Average	Operating cost per train mile	Cost of fuel	Wages paid for labor	Remarks	Average running speed
Great Western	Steam	250 55 tons including 1 trailer	0.13	Coal $3 ton	Driver 7s.	20 pounds per train mile	35 m. p. h.
North Eastern	Petrol-electric	85 35 tons	probably 0.15 to 0.16	30c gallon		3⅓ miles per gal. claimed (9c per mile fuel)	30 m. p. h.
Paris-Orleans	Purrey steam	260 50 tons including 1 trailer	0.08	Coke $6 ton	Driver $1.40	21 pounds coke per mile	35 m. p. h.
Arad Csanadar	Gans steam	35 About 40 tons including 2 trailers	0.075	Coke $5 ton	Driver about $1.20	9.6 lbs coke per per mile	25 m. p. h.
Arad Csanadar	Gasolene electric	70 About 20 tons	0.073	Gasolene 10c	Driver about $1.20	2.11 pounds gasolene per mile. 2.9 miles per gallon	35 m. p. h.
Arad Csanadar	Gasolene electric	35 About 40 tons including 2 trailers	0.057	Gasolene 10c	Driver about $1.20	1.61 pounds gasolene per mile. 3.75 miles per gallon	20 m. p. h.
Austrian State	Komarek steam	100 50 tons including 2 trailers	0.05	Coal $3.25	Driver about $1.20	15 pounds per mile	25 m. p. h.

Operating costs include, fuel, oil, repairs, and driver's wages.

DISCUSSION

PROF. W. F. M. GOSS The best machine is not always the lightest, and from such study as I have been able to give the motor car problem, I am convinced that for general service, even in light traffic, the motor car must eventually be coal fired. A motor car which is coal fired is bound to be confined to second class service. A single car which contains an engine, boiler, a supply of coal, and through which the trainmen, with soiled hands and clothing must be constantly passing, cannot be kept up to a satisfactory standard for high class service. Again whether employed in single units or made of sufficient power to handle trains. It does not appear that there is any material advantage either in cost of maintenance or cost of operating compared with that of a suitable locomotive drawing one or more cars. By suitable locomotive, I mean a steam locomotive of only sufficient power to do the service required. I believe that in reaching out for motor car service we are influenced a great deal by the success of the electric car and in so far as this may be the case, it will be well to remember that when we attempt to perform the service of an electric road by means of motor cars, difficulties are likely to appear. The service to which motor cars may be successfully applied is, in fact, very limited.

HARRINGTON EMERSON For repairs an engine must go frequently to the machine shop, a coach to the coach shop. The machine shop is no place for a coach, the coach shop no place for an engine. A detached engine is therefore advisable.

2 All railroads are accustomed to steam troubles and have a skilled force competent to cope with them. Any radical departure in the type of engine or even in design will entail a great increase of repair expense. Therefore, a steam engine is preferable to any form of gasolene engine.

3 Gasolene is in any case out of the question for general railroad use, because its price is very high and constantly rising and the supply insufficient. It is one thing to use gasolene for a few hours a week in the engine of a 10 to 30 h.p. pleasure car and quite another to use it on a regular train running ten hours a day, with a 200 h.p. engine.

4 The boiler, whether of the squat vertical type or of the usual locomotive type, should be fired with fuel oil. The remarkable results recently demonstrated on the largest freight locomotives weighing 235,000 lb. on drivers, in use on the A. T. & St. F. Ry.,

equipped with the Neely system of burning oil, show that not only is oil consumption reduced but repairs as well as flue and firebox troubles can be made less than on standard coal burners of similar types. The oil is of course more convenient, as well as cheaper.

5 It is difficult to understand why the New York Elevated Railroad type of tank engine, redesigned for oil burning, should not solve the experimental part of the problem of railway motor cars until the greater problems of need and cost of this kind of service have been worked out.

WILLIAM FORSYTH The article by Mr. Gray is especially valuable in that it gives the details of European practice.

2 The writer agrees with Mr. Emerson that it is not desirable to combine the engine with the coach on account of the repairs to the engine which must be made in the locomotive repair shop, where the coach is very liable to be injured.

3 A great many locomotive engineers have come to the conclusion that a small locomotive, to which a coach suitable for the desired purpose may be attached, is the best for handling light traffic. In England and Germany the locomotive builders build small locotives for this purpose, while in this country they use an old engine of the ordinary type, which has a large tender, is heavy, and is not economical, or suited to such work.

4 Although the writer holds that the steam locomotive is the best motor, it must be admitted that Mr. McKeen of the Union Pacific has been very successful in developing the gasolene motor. In nine of these cars which this company has built the motors are working very successfully.

5 In America the whole subject is in the process of development, and the writer believes it will ultimately be found that in some localities the gasolene or other oil motor will be the best adapted, but for general use the small steam locomotives will be the solution of the problem.

MR. C. D. YOUNG I want to say one word in defence of the position the railroads have taken in the matter of the slow introduction of the motor car in the United States. I believe the Erie Railway and the New England Railway were the first companies in this country to introduce this type of car for the kind of service; these two cars being built about 1897, the Erie car seating 45 passengers, whereas the New England car was somewhat smaller and seated but 40 passengers. The motive power of the cars was furnished by steam engines, the steam being generated in vertical boilers burning coal. About one year later the Baldwin Locomotive Co. built a few cars for the various railroads, using the Vauclain type of compound engine with magazine fed boiler, burning coal. All of these cars failed in operation, due, principally, to lack of steam capacity for the service required of these engines. Within the past three years the subject has again been revived and experimental motor cars are, or have been, tried by such roads as the Union Pacific, Chicago, Rock Island & Pacific, Chicago Northwestern, Chicago, Burlington & Quincy, Delaware & Hudson, Lake Shore & Michigan Southern, Delaware, Lackawanna & Western, and Erie; the results obtained in the operation of these cars have not been very satisfactory. I believe, however, the most successful design and that which will ultimately prove a success for this type of car, will be a water tube boiler furnishing steam for engines mounted on the trucks.

2 I recently made a report on the subject of motor cars, and I am frank to confess that my conclusions were that for trunk line railroads, with branch lines, the present traffic conditions would not warrant a very extended purchase of motor cars for several reasons. Most State laws require that a crew of at least four men be used on a train on any steam road; from this it is to be seen that for a single car, the operating expenses are almost prohibitive. This is not true of the street car or interurban business, where but two men to the crew are required. In order to develop an interurban business on a steam road, frequent service is absolutely essential; this too, is almost impossible owing to insufficient trackage. A service of this kind introduced on most steam roads today would badly handicap moving the present business. The carrying of gasolene or fuel oil on motor cars is a constant source of danger, in case of fire.

3 As most steam roads have a great number of light locomotives which are unfit for the present heavy trains, I believe that in the development of frequent service, the best arrangement would be to follow the example of the Illinois Central Railway in handling suburban traffic, that is of using their light locomotives and coaches rearranged and designed especially for the service.

4 Therefore, I do not believe that the self contained motor car will meet with any great success on American railroads, but rather when very frequent service is desired, they will make the step from the steam locomotive to the application of electricity, using electric locomotives on freight and through passenger trains and motor driven cars with multiple control for suburban service.

No. 1150

FLOW OF SUPERHEATED STEAM IN PIPES

By E. H. FOSTER, NEW YORK

Member of the Society

It is somewhat surprising that with the great number of installations which have been in practical operation there should be so little exact data available as to the flow of superheated steam in pipes. The lack of this information which is so much sought after is doubtless due to the fact that plants are usually constructed on a working basis and not for experiment. As an example, a battery of boilers all fitted with superheaters will deliver steam into a common header or equalizing pipe out of which steam will be taken at various points for the engines which are being served by the boilers. This usual condition of power plant piping permits a free exchange of surplus steam back and forth, according to the demands, and throws such a cloud of uncertainty over the actual velocities of the steam in the various pipes as to thwart effectually any attempt to get a correct accounting for the cause of any decrease in temperature or pressure. Also, at various plants the insulating covering differs perceptibly both in character and thickness. Occasionally, however, a situation is found where there is a run of pipe with a known quantity of steam passing through from which data may be obtained to throw light on the laws governing the flow of steam. From quite a large number of plants we have been able to collect enough data to indicate that the laws governing the flow of superheated steam differ appreciably from those governing the flow of saturated steam. A few general conclusions have been reached, as follows:

- *a* That the rate of heat transfer per degree difference in temperature per square foot of surface per hour increases with the steam velocity.
- *b* That this increase is more rapid in small than in large pipes.
- *c* That the percentage loss in heat decreases with the velocity, notwithstanding the rising rate of heat transfer.

Presented at the Indianapolis, Ind., Meeting (May 1907) of The American Society of Mechanical Engineers, and forming part of Volume 29 of the Transactions.

2 A high velocity of superheated steam in pipes is therefore recommended, because there is a smaller percentage of heat loss and because there is a lower actual drop in steam temperature.

3 The data at hand, while ample to show that the above conclusions are true, have not as yet been arranged sufficiently in detail to allow the formulation of a general law. It would be necessary to have a series of tests, conducted on a large scale, and on different sizes of pipes all covered in a uniform manner, in order to establish a formula covering the actual loss of temperature and pressure by superheated steam at different velocities.

4 Our practice is to recommend for steam pipes of straight runs or easy bends a velocity of 6000 to 8000 feet per minute where a superheat of from 100 to 200 deg. fahr. is used, and we have found these proportions to give very satisfactory results.

5 To substantiate the foregoing conclusions, the writer offers a few curves which have been constructed from a mass of notes collected from time to time; also a set of curves taken from a very excellent and complete paper read by Mr. O. Berner before the *Der Verein deutscher Ingenicure*, published in their Transactions of 1904.

6 This table is also given after being converted into English units. It is expected that these figures will be materially revised from time to time as more complete data on the various subjects are available.

TABLE 1

LOSS IN TEMPERATURE IN DEGREES FAHR. FOR 100 FEET OF PIPE (O. BERNER)

Av. steam pressure 176.5 lb.
Av. steam temperature 482 deg. f. 105 deg. superheat

DIAM. PIPE, IN.	VELOCITY OF STEAM IN FEET PER MINUTE		
	1968	3936	5904
3.937	50.3°	25.5°	16.45°
7.874	25.5°	12.7°	8.23°
11.811	17.0°	8.23°	5.49°
15.748	12.6°	6.07°	4.39°

Fig. 1 shows the rate at which the drop in temperature per hundred lineal feet of run of pipe decreases as velocity of steam increases, and is approximately correct for pipes from 6 to 10 inches in diameter.

Fig. 2 shows that the variation in rate of transfer of heat units per square foot per degree difference in temperature per hour increases almost directly with the velocity of the steam in the pipe, and varies for the different sizes of pipes and different kinds of covering. In pipes No. 1 and 2 a good magnesia covering was used; in No. 3 Keasby Magnesia standard thickness, and in No. 4 Magnesia 1½ inch.

Fig. 3 is a convenient diagram to show the required cross sectional area of a pipe passing 1000 pounds of steam per hour at velocities of 6000, 8000 and 10,000 feet per minute and at different temperatures and pressures.

Fig. 4 is a curve constructed from figures given by Mr. O. Berner.

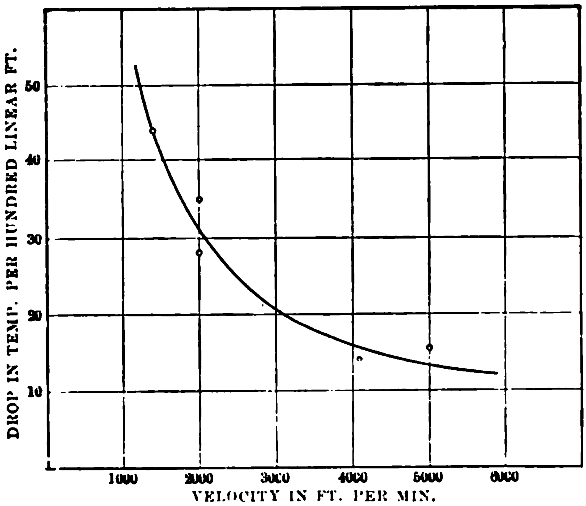

FIG. 1 VARIATION IN DROP IN TEMPERATURE IN SUPERHEATED STEAM LINES, WITH VELOCITY

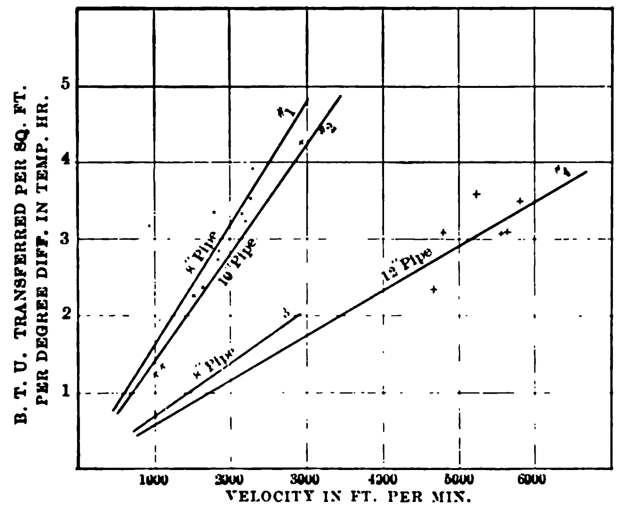

FIG. 2 VARIATION IN HEAT TRANSFER IN STEAM PIPES, WITH VELOCITY

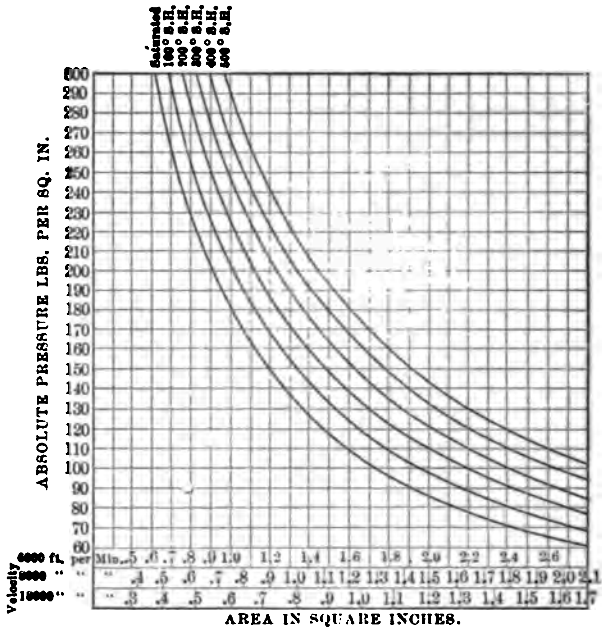

FIG. 3 AREA OF PIPE REQUIRED TO PASS 1000 POUNDS OF STEAM PER HOUR

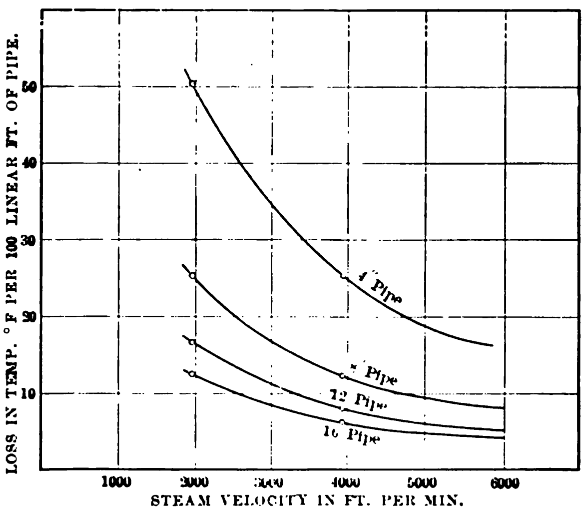

FIG. 4 LOSS OF TEMPERATURE IN SUPERHEATED STEAM LINES WITH SIZE OF PIPE AND VELOCITY OF STEAM

DISCUSSION

MR. HOSEA WEBSTER We note from Mr. Foster's paper—

a That the rate of heat transfer per degree difference in temperature per square foot of surface per hour increases with the steam velocity.

b That the percentage loss in heat decreases with the velocity notwithstanding the rising ratio of heat transfer and

c That high velocity of superheated steam in pipes is therefore recommended, because there is a lower actual drop in steam temperature.

The logic of these statements seems faulty and might lead to a misunderstanding, but this would not be an unusual experience for any one who has tried to draw reliable conclusions from published and observed data regarding the properties of superheated steam.

2 Mr. Foster's tables and diagrams are valuable as an addition to reliable records of observed conditions but as he states in his paper: "It is expected that these figures will be materially revised from time to time as more complete data on the various subjects are available." The loss of heat and energy incidental to the transmission of superheated steam from the boiler to the engine is a question of the greatest importance, and one of which little is accurately known today.

3 During the year 1904, Dr. Otto Berner published in the *Zeitschrift des Vereines deutscher Ingenieure*, an elaborate discussion of this subject, his investigations having been conducted at the request of the Society of German Engineers. While Dr. Berner presented and discussed a large amount of data which he had collected from tests by various observers, he frankly stated that he was unable, owing to the lack of exact information, to reach definite opinions as to the effect of the number of factors in this complex question, his final conclusions being that, while much information is available as to the generation of superheated steam and as to its action in the engine, we are still, with regard to its exact behavior during transmission, practically groping in the dark.

4 Erroneous deductions have unquestionably been drawn from superficial consideration of the data presented by Dr. Berner, but it is very clearly shown by his observations and by those of others, that, almost without exception, pipe systems conveying superheated steam convey more or less water of condensation. All evidence points to the fact that, excepting where the cooling is

excessive, the steam in the transmission pipe has a superheated core and a gradually falling temperature outward, until there is an annulus of condensate on the inner surface of the pipe.

5 The great variation in the conclusions to be drawn from published data regarding the physical properties of superheated steam, indicates that there is some defect in the methods used in making observations, and it is probable that the errors are mainly due to the great difficulty which has been experienced by almost all observers in determining the temperature of the superheated steam. The fact that almost without exception pipes conveying superheated steam contain more or less water of condensation, raises the question whether the temperature of the pipe itself exceeds the temperature due to the pressure carried. This at once gives rise to the question whether sufficient care has been taken so to insulate the thermometers used in making temperature observations of superheated steam as to prevent errors due to the cooling effect of the pipe walls.

6 The great difference of opinion among careful observers as to the specific heat of superheated steam, for instance, would seem to indicate that there is some property of superheated steam which has not as yet been discovered. The great interest which is shown by the presentation of so many papers at the meeting is certainly encouraging, and it is suggested that in making tests of transmission of steam through pipe systems, observations should be made along the following lines:

a Hourly steam weight conveyed through the pipe;
b Hourly condensation in the piping;
c Steam pressure at the beginning and end of the pipe line;
d Steam temperature at the beginning and end of the pipe line, where observations refer to superheated steam;
e Quality of steam at the beginning and end of the pipe line, where observations refer to saturated steam.

7 In making temperature observations with superheated steam, if mercurial thermometers are used, some means should be provided for protecting the thermometer and thermometer walls from the temperature of the pipe walls, which apparently does not bear any fixed relation to the temperature of the steam flowing through the pipe in the case of superheated steam.

Prof. D. S. Jacobus Mr. Foster tells us in presenting his paper that his conclusions were based on a portion of the data which he presents and that he now finds they do not agree with all of the data. It is this disagreement to which Mr. Webster refers when he says that the logic of some of the statements seems faulty. The conclusion arrived at by Mr. Foster, that the radiation increases with the steam velocity, is certainly not borne out by Dr. Berner's figures which are given in Table 1 of Mr. Foster's paper, as in this table the radiation loss per square foot of pipe surface is assumed by Dr. Berner to be constant. Furthermore Dr. Berner says in his paper "The few tests with different speeds in the same pipe system almost all show, even for great speed differences, only small differences in the heat loss," and cites the tests of Schröter where the values for the higher velocities were sometimes greater and sometimes smaller than for the lower velocities.

2 Dr. Berner's paper brings out the following point which is usually overlooked: that the heat lost through radiation in transmitting superheated steam for power purposes, is not exactly comparable with the heat lost with saturated steam. With saturated steam any heat lost by radiation produces water of condensation, and the heat which remains in the water of condensation is not available for producing work, the water in most cases being separated from the steam before it passes to the engine. With superheated steam, however, there is less loss in the heat contained in the water of condensation, and although the total heat loss through the radiation may be greater for the superheated steam than for the saturated, it does not follow that the loss of heat available for the production of power is necessarily greater.

MR. FRANK KOESTER[1] Mr. Foster's paper is an able one, and certainly throws more light on the flow of superheated steam. It could be made more complete, however, by adding a chart showing the volume of superheated steam at various pressures and temperatures.

2 Herr Berner in his paper before *Der Verein deutscher Ingenieure* calculated the volume of superheated steam from the Zeuner formula, a formula which is practically exclusively used throughout the continent of Europe, owing to the fact that it is the most accurate and the simplest.

3 It is as follows:

$$p_1 \, v_1 = R \, (t_1 - 273) - C \, p_1 \, n$$

[1] Member *Verein deutscher Ingenieure.*

in which p_1 = pressure of steam in kg. per sq. cm. absolute,

(14.7 lb. per sq. in.)

t_1 = temperature of superheat (cent.)

v_1 = additional volume in cubic meters

R, C, and n are constants, which for p are expressed in kilograms per square centimeter, and for v in cubic meters.

$$R = 0.00509 \qquad C = 0.193 \qquad n = 0.25$$

4 From this formula, the chart shown in Fig. 1, giving the volume of superheated steam for various degrees of superheat, has been laid out and converted to the English system. The dotted curve represents the volume of saturated steam, and the solid curves the volume of superheated steam, at the given total temperature.

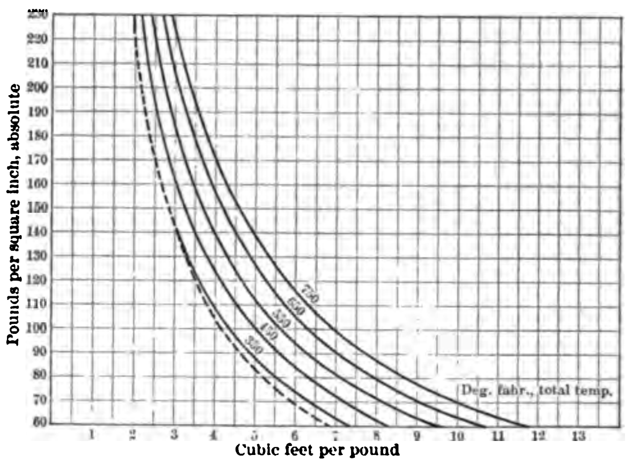

FIG. 1 VOLUME OF SUPERHEATED STEAM

5 To compare this chart with that in Fig. 3 of the paper, let us assume an absolute steam pressure of 185 lb. and a total temperature of 550 deg. fahr. (175 deg. superheat). It will be found that the volume is 3 cu. ft. per pound. In order to transmit 1000 lb. of steam per min. at a velocity of 6000 ft. per min., a pipe area of 72 sq. in. (say 10 in. diameter) will be required.

6 Now take Mr. Foster's chart and assume the same conditions. Following the curve down to the line giving areas for the given velocity, it will be seen that an area of 1.17 sq. in. is required for 1000 lb. per hour, or 70.2 sq. in. for 1000 lb. per min. (9½ in. diameter). This would mean a 10 in. pipe.

Mr. August H. Kruesi I want to ask Mr. Foster if the steam velocity of 6000 to 8000 ft. per min. which he recommends, is the normal velocity at rated load. These figures must, of course, depend on whether they refer to steam engines or steam turbines. They would probably be high for small engines, and, on the other hand, for steam turbines the maximum velocity may go considerably higher. The steam pipe sizes for Curtis turbines are based on a velocity at rated load, running condensing, of about 4500 ft. per min., which would correspond at maximum output to, roughly, 10 000 ft. per min.

Mr. Max E. R. Toltz This paper is very valuable. Up to the present time there has been a lack of information regarding the loss in transmitting superheated steam in steam pipes. Mr. Berner was the first one to make extensive tests in regard to this matter, but in his conclusions he says that, on account of the doubtful and varied results he had obtained, more work should be done in this line.

2 I made a test very recently on a steam pipe 800 feet long, with superheated steam at the pressure of 90 lb., superheat 100 deg., and I found that when the velocity of the steam was 100 ft. per sec. or 6000 ft. per min., the loss per 100 ft. was between 6 and 7 deg.; with a velocity of 50 ft. per sec. or 3000 ft. per min., the superheat was lost entirely. My experience has been especially with locomotives, and I found, although the connection from the dry pipe to the steam chests was very short, that the loss of temperature in steam, superheated to 100 deg. was between 15 and 40 deg.; in steam superheated to 200 deg., the loss was from 10 to 25 deg., all depending upon the velocity of the steam. In one instance, that of a Pacific type passenger engine, it developed that when running at a speed of 55 miles per hour, the steam attained a velocity of 234 ft. per sec., and in that case the loss of superheat was only 10 deg., while with a velocity of less than 150 ft. per sec., the loss of superheat was from 12 to 30 deg

3 I would like to make a motion, if it is consistent with the rules of the Society, to have a committee appointed to conduct further tests in this line so we will have better and final results. We are much at sea at present, and results derived from extensive tests would materially assist us in determining the degree of superheat to be added on account of long pipe lines.

Mr. Kinealy You spoke of a velocity of 200 ft. Can you tell us the pressure?

Mr. Toltz 165 pounds boiler pressure.

Mr. Kinealy The size of the pipe?

MR. TOLTZ The pipe was about five or six inches in diameter.

MR. KINEALY And the probable loss for the lower velocities?

MR. TOLTZ It was only ten pounds between the boiler and the steam chest. The pressure was not lost in the pipe, but in port openings of the valves. We found later that the port openings in the valves of this engine were too small. On an indicated diagram, we noticed at once that something was wrong, and it was intended to enlarge the port openings or make double openings. I think that in a six inch pipe with proper openings the steam would not have attained the velocity of 234 ft. per sec.

MR. KINEALY Then it becomes a question of whether it is better to have a loss in superheat or a loss in pressure.

MR. TOLTZ We have solved that question in another way. The saturated steam locomotives on the Great Northern run with a boiler pressure of 200 lb. per sq. in., while the superheated steam locomotives carry only 165 lb. per sq. in., but the cylinders of the latter were increased from 22 in. to 25½ in. in diameter. They are able to pull about 6 per cent more load with superheated steam than the saturated steam locomotives, which is simply due to the high starting power of the superheated steam engine.

THE AUTHOR The Society I think is to be congratulated on the action which it has just taken in appealing to the general government for the purpose of having determined definitely the values for the specific heat of superheated steam under all conditions. This should clear up the situation to such an extent that calculations could be made with a degree of exactness not hitherto possible. It is to be hoped that the government will grant the request of the Society, and that the determination will be rendered at an early date.

2 There seems to be some difficulty in understanding the relation of my two conclusions, as cited by Mr. Webster. The rate of heat transfer may increase at the same time that the percentage of heat loss decreases. Increased velocity means a higher total, but a lower heat loss expressed in percentage, because the rate of increase in the total amount of steam transmitted, due to an increased velocity, rises more rapidly than the corresponding total heat loss.

3 The possibility of steam pipes carrying both superheated steam and water has been mentioned. In a recent paper by A. L. Mellenby, Sc.D., for the West of Scotland Iron and Steel Institute, this condition was also noted. The author confesses that he has never yet had occasion to observe the existence of water in superheated steam lines. If it can so exist, as others seem to think, it must certainly

be only in pipes having a very low velocity of steam, and by careful designing, provision could be made to relieve the pipe line of the water, or to insure a mixture with superheated steam which would cause the water to be evaporated.

4 Mr. Koester in his discussion spoke of a diagram of the volume of superheated steam at different temperatures. I might say this information is really included in my table of velocity of superheated steam in various pipes. The net areas of and the velocities in the pipes are given. The volumes may be deduced from these.

5 Mr. Koester also asks why the rate of 6000 ft. per min. was recommended. My idea is to recommend 6000 ft. per min. at rated load, which allows for the usual overload of from 30 to 50 per cent. In case an overload of 100 per cent must be provided for, I would recommend a normal velocity in pipes of 4500 ft. per min. at rating, which would bring the velocity up to 9000 ft. per min. maximum. While talking with different foreign manufacturers of turbines in Europe last year, I was much impressed with the importance which they attached to the value of superheated steam in increasing the capacity of a turbine. The opinion seemed to prevail that about twice as much power can be gotten out of a turbine with superheated steam as with saturated steam.

6 May we not say that the advantage of superheat in turbines is mechanical, whereas the advantage in engines is thermal? Alexander Jude in his treatise on the steam turbine devotes much time to the discussion of the effect of superheat on turbines. He cites those losses in turbine economy which are favorably affected by superheat, as: condensation of steam over and above that due to expansion; the shock on vane edges and similar places; surface friction of the wheel discs; surface friction of the vanes; and ventilating friction.

7 With regard to the experiments for the determination of specific heat, I know that other investigations are now being carried on. I took part in making an apparatus for Professor Kent, who is now conducting a series of experiments in Syracuse, and I expect that before six months have passed we shall have an additional set of results.

8 I have noticed that in separately fired superheaters it is hard to justify the assumption of a high specific heat with the amount of fuel consumed, as this would tend to bring the efficiency of the superheater higher than a comparison with the performance of boilers will justify. For instance, if the specific heat of 0.7 is attributed to superheated steam at 160 lb. pressure and 200 deg. superheat, the superheater which Mr. Barrus refers to would have an

efficiency of about 75 per cent, which I think is doubtful. If, on the other hand, a specific heat of 0.6 or less is assumed, the efficiency of the superheater would fall to about the point which might be expected for an apparatus which must necessarily discharge its waste gases at a temperature at least as high as that of the boiler.

9 I do not agree with Mr. Kellogg in regard to the great difference between pipe lines for carrying superheated and those for carrying saturated steam. I think if a line were to be drawn it should be between moderate superheat and high superheat. A pipe line which is carrying a moderate superheat of a temperature of 500 deg. fahr. would not differ materially from one carrying saturated steam at 150 lb. pressure.

10 I think too much importance has been attached to alleged difficulties in joints, gaskets and valves, caused by superheated steam. I have seen several plants which were built 10 or 15 years ago for saturated steam, which have been recently equipped with superheaters, and the same pipe lines utilized for steam at about 500 deg. fahr. without a single change being made. On the other hand, I have heard of several instances where pipe lines have been affected by high temperatures, but whenever I have had an opportunity to investigate, I have found the trouble to be due to occasional excessive temperature.

11 In regard to cast iron, I do not find this so objectionable for fittings and pipe lines; in fact I rather favor its use in a great many instances. Mr. Kellogg speaks of deterioration of cast iron; I know of a great many cast iron fittings which have been in use for 16 to 18 years with superheated steam, and they are in as good condition as when they were installed. I also know of some cast iron superheaters which have been in use in this country for several years, subjected to average temperatures of 1000 deg. fahr. or more, which are now in good condition. It is important to use good cast iron. Difficulties attending the obtaining of cast steel which is not porous is one of the chief drawbacks to the use of this metal.

12 The chief difference between a pipe line carrying superheated steam and one carrying saturated steam, is in the amount of expansion and contraction due to changes in temperature, which will be greater in the former; and on the assumption that pipe lines are at best not too carefully put together, with an inadequate allowance for expansion and contraction, the strain on the joints of a superheated steam line will naturally be greater than on those of a saturated line. Too much reliance, in my opinion, has been placed on the flexibility of steel pipe bends, which are extremely rigid, particularly when made

of extra heavy pipe, and which would have a tendency to distort themselves when heated.

13 As to gaskets, I think one can not draw a line very closely about a certain type, and exclude others which have been very successfully used with superheated steam. I have heard of instances where corrugated copper gaskets have done well with both saturated and superheated steam, and I have also heard of instances where the same kind of gaskets have not done at all well with either saturated or superheated steam. My own practice is to use a thin corrugated bronze gasket, which has thus far been universally successful with steam at any temperature.

14 The author wishes to thank the members who have taken part in this discussion for the interest which they have shown in the subject, and hopes to see many other papers presented to the Society, as new data relating to the performance of superheated steam is secured.

application of superheat to any steam supply, stable
ıre or extent of added heat would appear to be a primary
but with the present forms of arrangements for the purpose,
to be far from achievement.

›ntrol of the temperature would in many cases be an addi-
'antage, and the attention of designers is evidently tending
is feature.

ıay therefore be of advantage to bring together some of the
:ions bearing on this subject with a view to a more general
ı the methods of generating superheated steam.

t of our present practice appears to be based upon the
n of superheating apparatus to standardized forms of
d settings, a leading consideration being the avoidance of
ce of their accepted designs, or alteration of the accepted
f boiler parts.

ıas thus become very common practice to install super-
ırface in some one position in the gas passages, where a
ess convenient space exists in a standard design, without
gard for its full desirability, or for a well adapted relation
perheating surface to the path or travel, volume, or tem-
›f the gases.

ıifestly, if existing designs of boilers and settings are to be
hered to, this must be the case, but it would seem that the
aim should rather take the direction of a remodeling of the
both boiler and setting, in favor of the superheating appa-
l that the latter should receive a greater consideration than
t very secondary position in the combination.

ent, is by no means to be regarded as a complete solution of the problem.

8 In such a position, not only the design of the superheater, but often its true proportion may be sacrificed to the exigencies of boiler proportions, and its accessibility, so peculiarly necessary, becomes questionable.

9 Placed thus, or in any other position where the travel of the main body of gases from the fire envelopes the heating surface, the superheater is subjected to conditions of wide variation of gas passage and temperature, largely increasing and decreasing its output in transferred heat.

10 If its proportions be based upon a given heat transfer to a given rate of steam passage through its interior, then the addition of green fuel to the fire, or other sources of heat variation there, may affect its output to a very wide degree, probably more than could be recorded by any thermometric appliance, and with consequent wide variation in cylinder effects.

11 The operation of an ordinary furnace is subject to so many variable elements in the nature of the fuel, its combustion, draft regulation, door openings, ash and clinker accumulations, and in the human elements back of all, that so sensitive an apparatus as that which is required to add heat to high-temperature steam should be protected as far as possible from these fluctuating influences.

12 Every engineer who has conducted boiler tests will agree upon the subject of gas fluctuations, in spite of the greatest care and expertness in hand-firing, and even to some degree with the use of automatic stokers.

13 The results would be comparable, though in a greater degree, to the inverse operation of condensing steam in a forced draft air system, in which the steam coil should be subjected to a draft varying considerably in volume, excessively in temperature, and being at the same time irregularly directed upon the tube surfaces.

14 It is not an answer in full to these conditions, so to construct a superheater, that an increase in the mass of material in its composition or in its walls or setting shall be provided, so as to absorb and give off heat to make up an average temperature condition.

15 Consideration in this direction should extend also to the furnace, and take the form of arrangements designed to eliminate the fluctuations of gas flow and temperature.

16 Automatic firing may do much toward such a result, but even more appears to be realizable by the provision of some form of rever-

beratory construction, in which masses of brickwork in the form of arches or walls alternately absorb and give out excess heat.

17 Several recent modifications of furnace design appear to lead in this direction, and may evidently be productive of relatively beneficial results on the steam-generating, as on the superheating surface.

18 Arrangements are capable of combination with certain types of boiler settings, in which the superheater is provided with a separate gas-flue from the fire, with a by-pass connection to some point in the main flue or passage beyond it, which by suitable dampers may be capable of a regulation of the volume of gas passing through the superheater. If provision could be practicably added for control of the gas volume by means of apparatus affected by the temperature of the gas, the output of superheat would become a defined quantity with a given steam-flow, but with the high temperatures involved, this does not seem to be realizable.

19 Fluctuations in the steam output of the boiler would moreover, still affect the degree of superheat, although this element is one that is partly controllable by existing apparatus, inasmuch as additions to the boiler output follow on additional furnace work, so that some modification or adjustment of the rate of gas flow over the superheater could probably be intelligently made by hand.

20 These considerations become more defined as the higher temperatures of superheat are attempted, and probably as much of the disappointment experienced in this direction is due to the lack of proper heat control, as to any other feature. The work of heat-transfer becomes rather closely balanced when steam is being superheated to the high degrees frequently employed in Europe, and when gas of relatively high temperature is necessarily being utilized for the work. Such relatively high temperature may, upon a comparatively moderate disturbance of the furnace conditions, such as the introduction of fresh fuel, fall temporarily to the degree where very little heat transfer to the steam will take place, and thus the steam supply of a delicately adjusted engine is suddenly reduced very largely in temperature, and its internal work, and its metallic expansion, much and undesirably modified.

21 It may not be too much to say, therefore, that for effectively securing the higher temperatures of superheat, the furnace conditions must be such as will eliminate the fluctuations of gas flow and temperature, or the heater must be placed where control of the gas volume can be secured.

22 As regards the maintenance of a given superheat at various outputs of steam, it may be said that where the relation between the

furnace heat-output, the first heating-surface of the boiler, and the superheating surface is well related, it seems reasonable to expect that variations in total steam supply would show little variation as regards the superheat, since the increase of furnace heat would be relatively absorbed by both the surfaces referred to. This would however, be modified when higher degrees of superheat are in use, in which case less of the boiler's primary heat-surface must be interposed between the fire and the superheater, and relatively less of an increase of heat would be absorbed thereby, subjecting the superheater to a relatively higher temperature, disproportionate to output.

23 Desirable results seem on the face, to be more readily attainable in the separately-fired type of superheater, but in this form of the appliance the separate furnace is subject to many of the same effects of fluctuation, due to fuel, draft, and handling, that a main boiler furnace would be. Moreover, the temperature at which the gases of a separate fire must pass off from the apparatus involve some loss in heat. This escaping heat might in some cases be utilized in an economizer, or as, in the recent proposal of Mr. Hosea Webster, Member of the Society, these gases might be connected into the boiler gas-passages at some suitable point, and be thus utilized in steam generation.

24 An ideal condition would, perhaps, be attained by a gas-fired independent superheater connected in this manner to the boiler, a refinement not, however, generally practicable, and thus for general practice it is necessary to rely upon the development herein advocated of the furnace control by such combination of grate, arch, walls, combustion-chambers, and draft, as will to the greatest extent regulate the flow of heat.

25 The problem is one in which the designer and manufacturer of every type of boiler is interested, and which they cannot be too strongly urged to take in hand.

26 The evident trend of general steam practice is toward the use of some degree of superheat, and the boiler of the future may thus be regarded as a combined apparatus, involving fuel, air, furnace, generator and superheater, supplying with the same regularity and security with which commercially dry steam is now delivered, a superheated steam of defined quality, in any quantity up to its extreme capacity.

27 Such a combination requires not only on the part of the designer but on that of the operator and user, some greater degree of attention and interest than has hitherto been bestowed upon the subject, and we may look forward to the time when the present methods

of haphazard combinations of fuel, chimneys, grates, boilers, and superheaters, often brought together without any co-relation, and even without any distinct object, will be exchanged for a policy in which the great boiler manufacturing interests will present, and the general body of steam users will appreciate defined combinations of the furnace with superheating generators, developed from the information and experience which has been accumulating about the subject in recent years.

DISCUSSION

MR. J. ROWLAND BROWN I do not wish to enter into a long discussion of the relative merits of the boiler setting and the independently fired superheater, but merely to state some observations made in experimenting, operating and designing superheaters of the former type.

2 I believe I am safe in stating that the standard type in this country is that in which the heating surface is contained within the boiler setting. The boiler setting type requires no additional space for its installation over that of the simple boiler, except in cases where high degrees of superheat are necessary and then an addition is made to the height of the setting. It requires no additional steam piping over the simple boiler except when it is desired to operate the superheater as a part of the water heating surface of the boiler. It has been customary to flood the superheater when raising steam or whenever the flow of steam through the tubes is stopped. In designs where the superheater is located at such a point in the setting that the average temperature of the gases does not exceed 1000 deg. fahr. it is not necessary to flood when raising steam if fair judgment is used. In one case a Babcock & Wilcox boiler was shut down every night and started up rapidly every morning without flooding and by a fireman who did not know what a superheater was. This superheater showed no signs of burning or leaking of the tubes. I have flooded and drained superheaters while the boiler was cut in on the load and never experienced any trouble from water hammer. The greatest danger of burning a superheater is when a boiler is being forced and for some reason is cut out of service.. The result is that the pop valves on the drums open and discharge the steam and there is no flow through the superheater, although a high temperature is maintained in the setting and if stokers are used this condition may continue for some time before it is checked. To guard against this condition, a pop valve is placed on the superheater outlet.

3 When a superheater of the boiler setting type goes out of commission it causes the loss of but one unit and the ratio of superheating to water heating surface in the balance of the plant remains the same. When an independently fired superheater goes out of commission it reduces the whole or at least a large part of the plant to saturated steam conditions.

4 The objection that the boiler setting type is subject to too great a heat fluctuation due to opening doors, draft, changes, etc., is not well taken, as the independently fired type is influenced to as much or greater extent. It is present practice to place the superheater about midway between the furnace and the damper; that is to say that the gases have passed over about one-half of the water heating surface before striking the superheater. Assuming a furnace temperature of 2500 deg., this means that the gases have fallen to a temperature between 1000 and 800 deg. when they reach the superheater. Repeated observations have shown that this temperature of the gases drops about 100 deg. when the furnace door is opened for firing and of course there is a greater drop in the furnace. The result is that although the heat transfer to the superheater is decreased, so also is the steam generated and the temperature of the steam shows but a small drop. The drop in steam temperature lags behind the drop in gas temperature and the amount of drop is a function of the time the door is open. Careful firing should not give a maximum variation of over 30 per cent of the degree of superheat at the superheater outlet. A superheater giving an average of 160 deg. would probably vary between 136 deg. and 184 deg.

5 Where a number of boilers are in battery the average superheat from all the boilers together will be very nearly constant, as the fluctuations will be distributed over different boilers at different times.

6 The superheater can be so designed that it will compound on overload: that is, the degree of superheat will increase with increase of load up to a certain point. One case showed an increase of superheat up to 30 per cent overload and then a slight decrease to 40 per cent, the curve falling off much less rapidly than it had increased.

7 In large units the boiler setting superheater as now designed does not average over 175 deg. superheat, although many are sold to develop 200 deg. In order to get the higher degrees of superheat it is necessary to get more space within the setting by an increase in the height.

8 One type of boiler places the superheater between the first and second rows of tubes directly over the furnace but protected by

tile. This design secures high superheat with minimum heating surface but there is considerable doubt as to the life of the tubes.

9 The following method of determining the ratio of superheating surface to boiler horse power for a given degree of superheat gives results very close to the actual. Mr. J. E. Bell has derived the formula

$$\frac{1}{(T - 378)^{0.16}} = 0.172\,H - 0.294$$

which is based on a saturated temperature of 378 deg. and a furnace temperature of 2500 deg. and in which T = the temperature of the gases at any point in the boiler and H – the per cent of the total heating surface between that point and the furnace. This curve gives the temperature of the gases at any point in the boiler if we know the per cent of heating surface passed over from the furnace to that point and also the temperature of the escaping gases. It has been checked by actual temperature readings and found to be quite accurate. After locating the position in the boiler at which the superheater is to be placed, the temperature of the gases striking its tubes can be secured from the curve.

10 The heat absorbed by the superheater per boiler horse power hour will be equal to 30 (the lb. of water per h.p. hour) $\times$ 0.5 (the specific heat of superheated steam) $\times$ S (the superheat in deg. fahr.).

11 Take 3 B.t.u. as the heat absorbed by the superheater per square foot per hour per degree difference between the temperature of the gases striking the superheater and the average temperature of the steam in the superheater.

12 The heat absorbed by the superheater per sq. ft. per hour will be three times the temperature difference. The average temperature of the steam in the superheater is taken as 378 deg. (the temperature of saturated steam at 175 lb.) + $\frac{1}{2}$ S (the degree of superheat).

13 The square feet of superheating surface per boiler horse power is equal to the heat absorbed per horse power divided by the heat absorbed per square foot. This formula reduces to

$$X = \frac{10\,S}{2\,(T - 378) - S}$$

This formula has been used in designing a line of superheaters and has given satisfactory results. It gives a basis for the design which must frequently be changed on account of local conditions which are not taken care of by the formula.

HOSEA WEBSTER Mr. Bolton presents a broad indictment of boiler manufacturers, the principal counts of which are:

a Superheaters are installed in most any convenient, inaccessible, out of the way space, and proportioned without regard to the travel, volume or temperature of the gases.

b That boiler manufacturers, failing to realize what a sensitive apparatus a superheater is, cruelly subject its anatomy to "variable elements in the nature of the fuel, its combustion, draft regulation, door openings, ash and clinker accumulations and the human elements back of all."

c That boiler furnaces, instead of being designed to meet efficiently the fluctuations in the consumption of steam, should be designed to give perfect uniform degree of superheat, regardless of other things, by eliminating, entirely, fluctuations of gas flow and temperature.

d That boiler manufacturers and steam users are not keen enough to get together and agree upon what constitutes good commercial practice in the design and use of superheaters.

2 Absolutely constant temperature of superheated steam is neither a commercial nor a theoretical necessity, though it may be desirable for an engine carrying a constant load. It is perfectly feasible to construct a combination of steam generator and superheater which will supply superheated steam of any desired constant temperature in varying amounts, if the purchaser will eliminate all limitations of elements of first cost and operating expenses, although judging by the variation in opinion as to the specific heat of superheated steam, there seems to be a very considerable variation in the heat absorbing properties of the output of various steam generators.

3 The temperature of the gas passages, and consequently the output of a steam generator, varies practically with the volume and temperature of the products of combustion. This accounts for the fact that almost universal practice places the superheater in the path of the furnace gases as near the furnace as practical limitations of durability and accessibility will permit, and where the changes in temperature of the superheater chamber are coincident with the variations in the furnace temperature and the consequent variations

in amount of steam to be superheated, combined with the additional fact that the time that a particle of steam occupies in passing through the superheater varies inversely with the temperature of the superheating chamber. That is to say, that though the heating surface of the superheater is constant, an increase in the production of steam follows an increase in furnace temperature which causes an increase in the temperature of the superheating chamber. This would cause an increase in the degree of superheat but for the necessarily increased rate of flow through the superheater with consequent reduction of time during which each particle of steam is subjected to heat. Therefore, the modern practice of locating a superheater in a convenient place in the boiler setting affords an example of an automatically controlled apparatus almost perfect in its simplicity and efficiency.

4 Slight variations in the temperature of the steam at the superheater outlet with variations of the output of the generator between fractional loads and heavy overloads do undoubtedly occur in practice, but they become practically insignificant in the great majority of plants by the time the steam reaches the engine throttle.

5 Present practice in the design and location of superheaters is the product of careful consideration of the problem by manufacturers and users, and it is safe to say that during the years of progress of steam power plants along the lines of increase in efficiency, no device has ever been so generally adopted which saves as much fuel, with as low first cost and operating expense, as the several standard superheaters of today.

6 Theoretical considerations of power plant economy, limited by the coal bunker at one end and the crank shaft at the other, are valuable as holding up the mirror of perfection, but the manufacturer is to a considerable extent governed in his standards by a regard for the fact that, though they are philanthropic and educational institutions to a greater degree than they are usually given credit for, both manufacturing establishments and power plants must be conducted with some degree of consideration for the profit and loss account.

7 As an example of what (to quote Mr. Bolton) "present forms of arrangement for the purpose of application of superheat to any steam supply" will do, the accompanying table of a test of one of the boilers in the Waterside Station of the New York Edison Company shows a reasonably stable temperature of added heat. Numerous examples of as good a performance could be cited.

8 As an indication of the opinion of users of boilers with superheaters located in the gas passage of the boilers, it may be interesting

to know that, in 1904, 36 per cent of the horse power output of the Babcock and Wilcox Company was equipped with such superheaters, 41 per cent in 1905 and 61 per cent in 1906, with the indications that the percentage for this year's business will be considerably greater.

9 That this paper reflects opinions prevailing to some extent today is unfortunately the fact, but the absence of evidence and data to substantiate the indictment of what is general practice in this country and abroad, is due to the fact that they do not exist

TABLE I

Showing the Performance of Babcock & Wilcox Superheater in Connection with Babcock & Wilcox 650 Horse Power Boiler, at the Waterside Station of the New York Edison Company

1	2	3	4	5	6	7	8	9	10	11	12	13	14
No. of test	Duration of test, hours	Maximum h.p.	Minimum h.p.	Average h.p.	Per cent builders' rating	Average smoke flue temp. deg. fahr	Average steam pressure lb. per sq. in. gage	Saturated steam temp. due to pres. deg. fahr.	Maximum observed superheat deg. fahr.	Minimum observed superheat deg. fahr.	Average temperature of superheated steam deg. fahr.	Average superheat deg. fahr.	Variation from 128.2 deg. fahr. Average superheat of 7 tests deg. fahr.
13	10	625	570	608	93.5	499	181.9	380.3	116.8	96.8	489.5	109.2	−14.0
3	9½	736	596	652	100.0	497	182.0	380.4	132.9	119.4	506.3	125.9	+ 2.7
4	10	760	620	693	106.6	521	182.0	380.4	151.0	126.0	516.3	135.9	+12.7
8	10	758	645	704	108.1	521	182.4	380.4	127.0	106.0	496.3	115.9	− 6.3
2	10½	870	663	767	118.0	515	184.0	381.0	139.0	109.0	500.0	118.9	− 3.3
12	10	950	717	800	123.0	532	181.8	380.0	135.0	118.0	508.8	128.8	+ 5.6
1	8	950	775	860	132.0	493	182.5	380.3	139.0	114.0	508.3	128.0	+ 4.8

and to the fact that there is no more a demand for the complications of design and cost of maintenance and operation absolutely necessary to accomplish what Mr. Bolton outlines, than it is a fact that modern practice is, to quote Mr. Bolton, "To place a superheating coil in a certain part of the gas passage of a boiler where a more or less convenient space exists in a standard design, without regard for its full desirability or for a well adapted relation of the superheating surface to the path or travel, volume or temperature of the gases, and connect the steam supply to it by strange and undesirable pipe connections."

10 Manufacturers always gladly welcome definite suggestions supported by facts, looking to the improvement in quality or effi-

ciency of their output, but this Society ought to protect them from the effect produced on minds of superficial readers by vague suggestions of a critical nature.

MR. AUGUST H. KRUESI Mr. Webster challenges some of the statements in Mr. Bolton's paper, and discredits the statements as to the amount of superheat being dependent upon the conditions of firing. I would like to offer a few figures in support of Mr. Bolton's statement, taken on 360 h. p. boilers, with combined superheaters; the observations being taken every twenty minutes during a 24-hour period.

Boiler no.	Maximum superheat	Average superheat	Minimum superheat
6	176	140	106
5	110	79	33
11	138	87	57

2 A fireman who could not hold his steam pressure steady within 25 pounds would not be worth keeping; but 25 pounds variation in pressure corresponds to only 10 deg. variation in temperature. The tests just cited exhibited a variation in temperature eight times as great. They were made on boilers in commercial service, hand fired, by the best fireman available in the locality; the station operating a variable railway load. It will be readily understood how difficulties arise with piping, valves and gaskets with such extreme variations in temperatures. Nothing like it was ever known with saturated steam, and I want to endorse Mr. Bolton's plea for more thorough design of combined superheaters.

MR. MAX E. R. TOLTZ Mr. Bolton's points showing the present defects of the relation of superheat to the furnace are well taken and should be considered by every one who has charge of steam plants which are being brought to a higher degree of economy by improving the steam. The superheaters now in use and located at random in present types of boilers do not come up to the high standard at which Mr. Bolton aims because the degree of superheat fluctuates according to the temperature of the gases flowing around them, yet these imperfections can be overcome by regulating the quantity of gases, which is accomplished by dampers arranged properly; but such regulation will have to be done either by hand or automatically. In some design of boilers, like the Heine or Franklin, it is by all means recommendable to locate the superheater either back of the bridge or at the end of the lower fire passage, in a double chambered reverberating furnace, in such manner that a certain amount of the gas must pass through such chambers. This has given good satisfaction relating to a uniform degree of superheat.

2 Relating to Par. 10 regarding high temperatures of superheat, the design of the superheater as well as its location must be considered. The heat transmission coefficient per degree of temperature difference is so variable that superheaters of present design transmit only from 2.5 to 3.6 B.t.u. per square foot per hour for one degree temperature difference, while in some cases superheaters of improved design have transmitted as high as 11 B.t.u.

3 Another factor to be considered is to design engines for high superheat differently than the present ones. Here again we get our lessons from Europe where not engines only, but also steam turbines are constructed on somewhat different lines for the use of *highly* superheated steam, the main object being to take care of the great and sudden stresses due to expansion and contraction.

4 Par. 23 reads: "Desirable results seem on the face to be more readily obtainable in the separately fired type of superheaters." What I like most in this sentence are the words: "on the face" which embody a whole history of bad moves made in this direction. No wonder that the engineers of our electrical companies make the statement that in steam turbines superheated steam will give a steam saving but no saving in fuel, which, of course, prevents many an engineer from improving the steam by superheating; but on investigation it will be found that separately fired superheaters were used in these tests which do not give the economical results of the ones built in the boiler. I will cite the results of tests made on a 5000 horse power triple expansion engine; condensing with superheated steam of different temperatures; pressure 199 pounds; temperature of the steam 381 deg. fahr.; cut-off, 4 per cent; piston speed, 16½ feet per second; automatic cut-off; four poppet valves; consumption of saturated steam per indicated horse power hour 11.82 lb.

Deg. fahr.	Per cent	Per cent	
144 superheat	7 steam saving	3.0 coal saving	part of boiler
144 superheat	7 steam saving	-8.0 coal saving	separately fired
216 superheat	13 steam saving	6.0 coal saving	part of boiler
216 superheat	13 steam saving	-4.5 coal saving	separately fired
288 superheat	19 steam saving	9.0 coal saving	part of boiler
288 superheat	19 steam saving	-1.0 coal saving	separately fired
353 superheat	22 steam saving	11.5 coal saving	part of boiler
353 superheat	22 steam saving	1.5 coal saving	separately fired

5 The engine developed 5000 indicated horse power at all times. The figures only show the gain in the engine proper, to which should

be added from 5 to 7 per cent gain in pipe line due to the use of superheated steam.

6 More prominent are the gains derived from superheated steam in a 250 horse power compound engine; condensing, pressure 142 lb., temperature of saturated steam 354 deg. fahr.; cut-off, 6 per cent; piston speed, 10 feet per second; automatic cut-off; four piston valves; consumption of saturated steam per i.h.p. hour, 15.73 lb.

Deg fahr.	Per cent	Per cent	
130 superheat	15.0 steam saving	11.5 fuel saving	part of boiler
130 superheat	15.0 steam saving	1.5 fuel saving	separately fired
202 superheat	20.0 steam saving	14.0 fuel saving	part of boiler
202 superheat	20.0 steam saving	4.5 fuel saving	separately fired
274 superheat	26.0 steam saving	17.5 fuel saving	part of boiler
274 superheat	26.0 steam saving	8.5 fuel saving	separately fired
338 superheat	28.5 steam saving	18.5 fuel saving	part of boiler
338 superheat	28.5 steam saving	9.0 fuel saving	separately fired

7 Here also the gain in the pipe line should be added.

8 At any rate a separately fired superheater should only be used where superheaters cannot be installed in the boiler proper, or where conditions are such that the superheater can be fired with the outgoing gases of furnaces, etc.

9 In addition to the requirements as laid down by Mr. Bolton a superheater should have the following points:

10 It should transmit the highest number of British thermal units per square foot of heating surface per hour per one degree temperature difference.

11 The headers or connections thereof should be outside of the hot gases and should be accessible at any time, so that a superheater element can be exchanged or renewed like a boiler tube.

12 The superheater should be so constructed that it is practically self-cleaning or in other words, that it will not be necessary to blow off soot and cinders with a steam jet.

THE AUTHOR The discussion which the paper has elicited has added to the available information upon this phase of the subject of superheating steam, and confirms the general proposition therein made, that the relation of the superheater to furnace conditions and variations is worthy of more detailed study and improvement.

2 Mr. Rowland Brown's observations indicate very clearly the methods of relating the superheating surface to the assumed gas temperature, but as Mr. Toltz points out, the coefficient of heat transfer is extremely variable, the range which he gives extending

from 2.5 to 11 thermal units per square foot per degree difference per hour.

3 I entirely concur in Mr. Rowland Brown's assertion that the independently fired superheater is affected as much as the boiler setting type by furnace fluctuations, and I think his statement of the drop in gas temperature due to door openings, may be regarded as very close to average conditions, but I would add that it must not be forgotten that the furnace temperature itself is fluctuating from other causes, so that the total effect of variation on the superheater is liable to exceed the 10 to 12 per cent which he has observed as a direct result of door openings, and thus account for the wide variation recorded in many tests.

4 The figures of variation in superheat given by Mr. Kruesi, form a very practical illustration of my main suggestions which, it is to be noted in response to Mr. Webster's characterization of my paper, were in no way intended to criticise any one form or type of setting or combination, and certainly not to discredit the excellent work so far accomplished by our leading boiler manufacturers, but to indicate the line on which further advance could be made, and in which the coöperation of steam users and manufacturers is invited.

5 The tests which are offered by Mr. Webster as an illustration of his contention that present conditions do not indicate need of improvement, are, when analyzed, actually confirmative of the desirability of the plea for improvement which I put forward, and a little examination of the figures, divested of the averaging which is so often a misleading element in such records, will indicate that the very features I suggested are present in these tests.

Test	Maximum rating per cent	Variation in boiler output per cent	Variation in superheat per cent
13	93.5	9½	20
8	108.0	17½	20

6 In the foregoing, at or near the rated capacity of the boiler, moderate fluctuations in output are accompanied by a regular extent of variation in superheat.

7 But as soon as the output is varied to a greater extent the furnace fluctuations are reflected in irregularities of superheat as follows:

Test	Maximum rating per cent	Variation in boiler output per cent	Variation in superheat per cent
4	106.6	22½	20
1	132.0	22½	22½
3	100	23½	11½

nd, when the fluctuations of boiler output become wider, the riations of superheat become erratic, as follows:

Test	Maximum rating per cent	Variation in boiler output per cent	Variation in superheat per cent
2	118	31	27½
12	123	32	14.4

No. 1152

ENTROPY LINES OF SUPERHEATED STEAM

TAKEN FROM THE EXPERIMENTS OF KNOBLAUCH AND JAKOB

By PROF. ARTHUR M. GREENE, JR., COLUMBIA, MO.
Member of the Society

The temperature entropy diagram is one of the most powerful aids in the study of the action of heat engines and it is of especial value in the investigation of engines, turbines, and refrigerating machines using volatile liquids as the working substance. For the cycles of refrigerating machines it may be applied rapidly to determine certain quantities and effects of proposed changes which would take considerable calculation; for the steam engine it may be applied to investigate the losses and interchanges of heat, while for steam turbines it may be used for the determinations of velocity in the different stages and to show how certain friction loss for one stage is available for the production of velocity change in the next stage.

2 The modern use of superheated steam for engines and turbines for the purposes of increasing the efficiency of the machines has necessitated the construction of accurate constant pressure lines in the superheated region of the entropy diagram for the investigation of the problems arising in the study of the heat interchange in the machine. It is true that one could figure out the net gain in pounds of coal per horse power without this but the detailed study can only be made when the lines are known.

3 These lines depend on the value of the specific heat of superheated steam at constant pressure, C_p. The value of this specific heat is necessary for the determination of the actual heat applied to bring steam into a given superheated condition. The value of C_p was considered as constant for a number of years, the value 0.48 determined by Regnault[1] being used. This was seen to be incorrect and a number of investigators attacked the problem. The results of Grindley and Griesmann seemed to indicate that the specific heat increased with

[1]V. Regnault, Mem. de l'Acad. des Sciences 26 p. 167, 1862.

Presented at the Indianapolis Meeting (May 1907) of The American Society of Mechanical Engineers, and forming part of Volume 29 of the Transactions.

the temperature and was independent of the pressure. This was found to be untrue in the various experiments of Lorenz, Linde, Holborn and Henning, Callendar, Carpenter, Knoblauch, and Jakob.[1] The results of the last named investigators are the best at hand and at present they should be accepted as correct. The experiments have been carefully performed and the endeavor has been made to eliminate all errors. Their investigation is indeed an excellent piece of work. Their original paper gives reference to the works of others and explains the differences between the conclusions and results of the various experimenters.

4 The results of their work have been given in the Zeitschrift des Vereins deutscher Ingenieure, vol. 51, p. 81 and 124, 1907. In this paper a diagram and table are given showing the results of the experiments. These are reproduced in Fig. 1 and Table 1, and give the results in a graphical and tabular form. The curves are constructed by extrapolation from the results of the experiments.

5 The curves show the value of C_p for different temperatures at different pressures. The values are expressed in degrees centigrade and in kilograms per square cm. of pressure and in heat units per unit weight per degree which is an abstract number. The table gives the values determined from these curves. The variation of the specific heat is shown very clearly, and the great variation accounts for discrepancies which have appeared in work done in earlier times.

6 Let the curve shown in Fig. 2 be one of the curves of C_p for a given pressure with the axis drawn through the zero values of absolute temperature and of specific heat. The area beneath the curve between the temperature of saturation and the temperature T_2 is equal to the heat added to change one unit of saturated steam at that pressure from the point of saturation to superheated condition at the temperature T_2. The equation for that is

$$H = \int_{T_s}^{T_2} C_p dt \qquad [1]$$

and this is represented by the area $T_sT_2 A''D$.

7 Equation 1 gives the amount of heat necessary for the change of one unit weight of steam from the saturation point to the superheated point T_2. This value could be used in finding the total heat required

[1]Grindley—Transactions of Royal Society, Vol. 194, Sec. A, 1900; Griessmann Zeitschrift Des Vereins deutscher Ingenieure, Vol. 47, p. 1852–1880; Lorenz, Zeitschrift des Vereins deutscher Ingenieure, Vol. 48, p. 698; Holborn and Henning Ann. d. Phys., 18 p. 739; Callendar, Proc. Royal Soc. of London, 67, p. 266, 1904; Carpenter, A. S. M. E., 1906–1907. See References by Knoblauch and Jakob.

TABLE 1

VALUES OF SPECIFIC HEAT BY KNOBLAUCH AND JAKOB

Zeitschrift des Vereins deutscher Ingenieure, Vol. 51

Values of C_p

Pressure p= Sat. tem. t=	0 kg.	1 kg. 99	2 kg. 120	4 kg. 143	6 kg. 158	8 kg. 169	10 kg. 179	12 kg. 187	14 kg. 194	16 kg. 200	18 kg. 206	20 kg 211
Temp. sat.		0.463	0.480	0.513	0.548	0.583	0.621	0.660	0.704	0.751	0.807	0.865
t = 100 C	0.447	0.463										
110 C	0.447	0.463										
120 C	0.447	0.462	0.480									
130 C	0.447	0.462	0.479									
140 C	0.448	0.462	0.477									
150 C	0.448	0.462	0.476	0.510								
t = 160 C	0.449	0.461	0.475	0.506	0.545							
170 C	0.449	0.461	0.474	0.502	0.536	0.582						
180 C	0.450	0.462	0.474	0.498	0.528	0.566	0.618					
190 C	0.451	0.462	0.473	0.495	0.520	0.552	0.594	0.648				
200 C	0.451	0.462	0.472	0.492	0.513	0.538	0.572	0.613	0.664	0.751		
t = 210 C	0.452	0.462	0.472	0.489	0.507	0.526	0.553	0.583	0.616	0.668	0.750	
220 C	0.454	0.463	0.472	0.487	0.502	0.517	0.535	0.558	0.582	0.614	0.662	0.731
230 C	0.455	0.464	0.472	0.486	0.497	0.509	0.522	0.538	0.557	0.578	0.607	0.649
240 C	0.457	0.465	0.472	0.485	0.494	0.503	0.512	0.523	0.536	0.552	0.570	0.596
250 C	0.458	0.466	0.473	0.484	0.491	0.499	0.506	0.514	0.522	0.532	0.544	0.559
t = 260 C	0.460	0.467	0.473	0.483	0.490	0.496	0.502	0.508	0.514	0.520	0.527	0.535
270 C	0.462	0.468	0.474	0.483	0.489	0.494	0.499	0.504	0.508	0.513	0.517	0.522
280 C	0.464	0.470	0.475	0.483	0.488	0.493	0.497	0.501	0.505	0.508	0.511	0.514
290 C	0.467	0.472	0.477	0.484	0.489	0.493	0.497	0.500	0.503	0.506	0.508	0.510
300 C	0.470	0.474	0.478	0.485	0.490	0.493	0.497	0.500	0.502	0.504	0.506	0.508
t = 310 C	0.473	0.477	0.481	0.487	0.491	0.495	0.498	0.500	0.502	0.504	0.506	0.507
320 C	0.476	0.480	0.483	0.489	0.493	0.496	0.499	0.502	0.503	0.505	0.507	0.508
330 C	0.479	0.483	0.486	0.491	0.495	0.499	0.501	0.503	0.505	0.507	0.508	0.510
340 C	0.483	0.486	0.489	0.494	0.498	0.501	0.503	0.505	0.507	0.509	0.510	0.511
350 C	0.487	0.490	0.492	0.497	0.500	0.503	0.506	0.508	0.509	0.511	0.512	0.513
t = 360 C	0.491	0.494	0.496	0.500	0.503	0.506	0.508	0.510	0.512	0.513	0.514	0.516
370 C	0.495	0.498	0.500	0.503	0.506	0.509	0.511	0.513	0.514	0.516	0.517	0.518
380 C	0.499	0.502	0.504	0.507	0.511	0.512	0.514	0.516	0.517	0.519	0.520	0.521
390 C	0.504	0.506	0.508	0.511	0.513	0.515	0.517	0.519	0.520	0.522	0.523	0.524
400 C	0.509	0.511	0.512	0.515	0.517	0.519	0.521	0.522	0.523	0.525	0.526	0.527

to produce one pound of superheated steam from water at the freezing point by the formula

$$\text{Total heat} = q + r + \int_{T_s}^{T_1} C_p dt \qquad [2]$$

This expression could then be used to find the heat supplied to an engine or other machine and from it the efficiency could be found. However this may be for general problem of efficiency, many of the problems are best solved by means of the entropy diagram and for

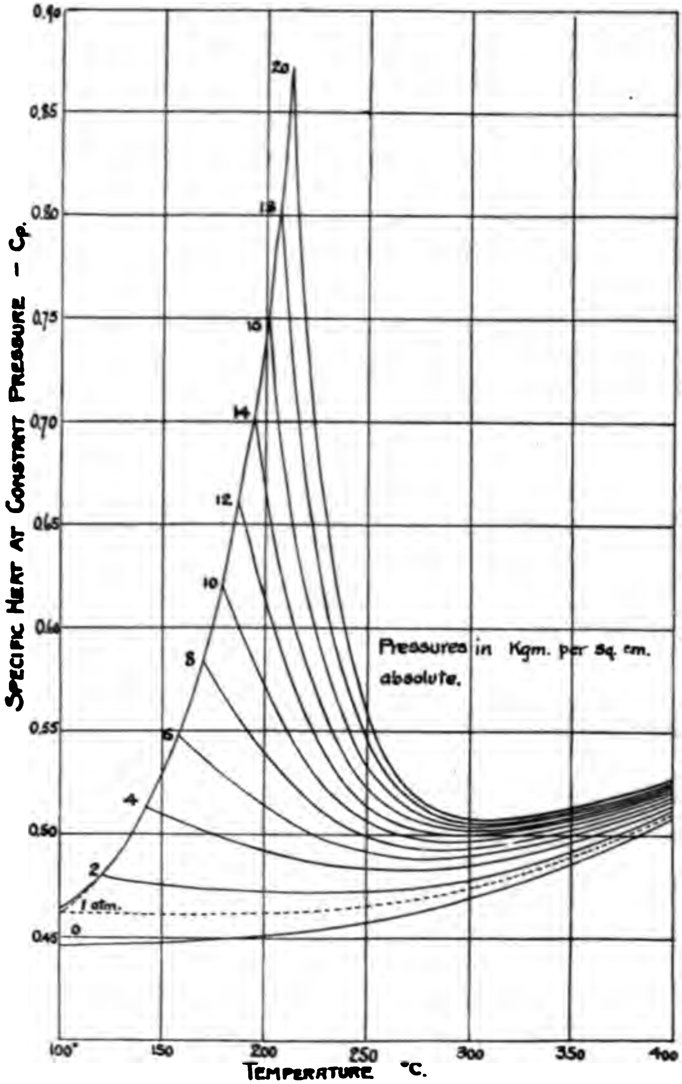

FIG. 1 VARIATION OF THE SPECIFIC HEAT OF SUPERHEATED STEAM

that reason it is necessary to construct the constant pressure lines in the temperature entropy diagram. From the definition of entropy it is known that the entropy change from the point of saturation to the point T_2 is

$$t_s\phi t_2 = \int_{T_s}^{T_2} \frac{C_p dt}{T} \qquad [3]$$

The integral in Equation 3 is the area of a curve whose ordinates have the value $\frac{C_p}{T}$ and whose abscissae are T.

8 A curve with ordinates $\frac{C_p}{T}$ may be constructed graphically as follows: From any point A in Fig. 2 draw a straight line to the origin. This cuts a vertical line through B at C. Let the distance OB be

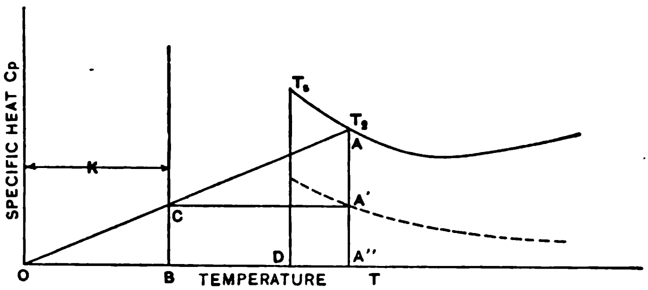

FIG 2 CONSTRUCTION OF CURVES FOR $\frac{C_p}{T}$

equal to K. Then since AA'' is equal to C_p and OA'' equals T, $BC = \frac{KC_p}{T}$. Draw a horizontal from C to the vertical line A, this cuts AA'' in A', the distance from the axis being $\frac{KC_p}{T}$. If a number of points A' are constructed in this way a dotted curve is formed whose ordinates have the value $\frac{KC_p}{T}$ and whose abscissae are T. The area of this for the limits of temperature above is

$$\text{Area} = \int_{T_s}^{T_2} \frac{KC_p}{T} dt = K \int_{T_s}^{T_2} \frac{C_p dt}{T} = K t_s\phi t_2 \qquad [4]$$

$$t_s\phi t_2 = \frac{Area}{K} \qquad [5]$$

9 Since the absolute zero is so far to the right, the simpler and more accurate method is to compute the values of $\frac{C_p}{T}$ and plot these. This has been done for the values of Table 1 and the values are given in Table 2 and Fig. 3. The limits of the curves on the left are the points of saturation. The curves are for different pressures in kilograms per square centimeter, although curves for 3 pounds per square inch, 5 pounds per square inch and 10 pounds per square inch have been interpolated.

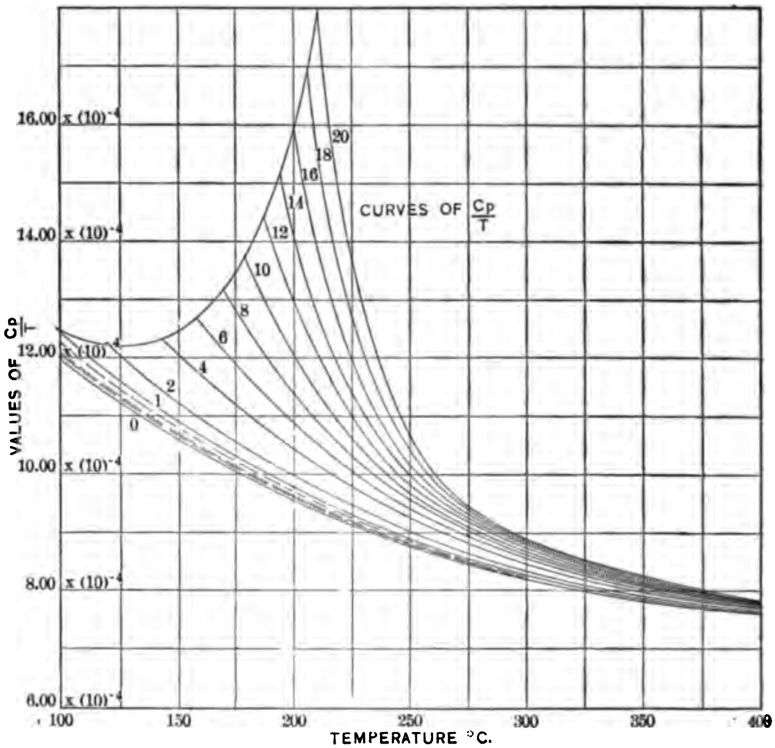

FIG. 3 CURVES FOR $\frac{C_p}{T}$

10 The reason for keeping the values in French units is that the original data are given in those units and that the entropy lines will have the same numerical change in units of entropy between corresponding temperatures in the French and English systems since, as expressed, the unit entropy per unit mass is a ratio and has no dimensions. This would only change the units on the temperature

TABLE 2

VALUES OF $\frac{C_p}{T}$ FOR STEAM AT DIFFERENT TEMPERATURES OF SUPERHEAT IN TEN THOUSANDTHS OF A HEAT UNIT PER POUND OR KILO PER DEGREE PER DEGREE

Degree C.	Deg. abs.	0 kg.	1 kg.	2 kg.	4 kg.	6 kg.	8 kg.	10 kg.	12 kg.	14 kg.	16 kg.	18 kg.	20 kg.
T. sat.	T. sat.		12.45	12.21	12.33	12.71	13.19	13.77	14.35	15.07	15.88	16.85	17.87
100	373	11.98	12.41										
110	383	11.67	12.09										
120	393	11.38	11.76	12.21									
130	403	11.09	11.46	11.89									
140	413	10.85	11.19	11.55									
150	423	10.59	10.92	11.25	12.06								
160	433	10.37	10.65	10.97	11.69	12.59							
170	443	10.14	10.42	10.70	11.33	12.10	13.14						
180	453	9.934	10.20	10.46	11.00	11.66	12.50	13.64					
190	463	9.731	9.978	10.22	10.69	11.23	11.92	12.83	14.00				
200	473	9.535	9.767	9.979	10.40	10.85	11.37	12.09	12.96	14.04	15.88		
210	483	9.358	9.565	9.772	10.12	10.50	10.89	11.45	12.07	12.75	13.83	15.53	
220	493	9.209	9.392	9.574	9.878	10.18	10.49	10.85	11.32	11.81	12.46	13.43	14.83
230	503	9.046	9.225	9.384	9.662	9.881	10.12	10.38	10.70	11.07	11.49	12.07	12.90
240	513	8.908	9.064	9.201	9.454	9.630	9.805	9.981	10.19	10.45	10.79	11.11	11.62
250	523	8.757	8.910	9.044	9.254	9.388	9.541	9.675	9.828	9.981	10.17	10.40	10.69
260	533	8.630	8.762	8.874	9.062	9.193	9.306	9.418	9.531	9.644	9.756	9.887	10.04
270	543	8.508	8.619	8.729	8.895	9.006	9.098	9.190	9.282	9.355	9.448	9.521	9.632
280	553	8.391	8.499	8.589	8.734	8.825	8.915	8.987	9.060	9.132	9.186	9.241	9.295
290	563	8.295	8.384	8.472	8.597	8.686	8.757	8.828	8.881	8.934	8.988	9.023	9.059
300	373	8.202	8.272	8.342	8.464	8.551	8.604	8.674	8.726	8.762	8.796	8.831	8.866
310	583	8.113	8.182	8.250	8.353	8.422	8.491	8.542	8.576	8.611	8.645	8.679	8.696
320	593	8.027	8.095	8.147	8.246	8.314	8.364	8.415	8.465	8.482	8.516	8.550	8.566
330	603	7.944	8.010	8.060	8.143	8.209	8.275	8.308	8.342	8.375	8.408	8.425	8.458
340	613	7.879	7.928	7.977	8.059	8.124	8.173	8.206	8.238	8.271	8.303	8.320	8.336
350	623	7.817	7.865	7.897	7.977	8.026	8.074	8.122	8.154	8.170	8.202	8.218	8.234
360	633	7.757	7.804	7.836	7.899	7.946	7.994	8.025	8.055	8.087	8.104	8.120	8.152
370	643	7.698	7.745	7.776	7.823	7.869	7.916	7.947	7.978	7.994	8.025	8.040	8.056
380	653	7.642	7.688	7.718	7.764	7.825	7.841	7.871	7.902	7.917	7.948	7.963	7.979
390	663	7.602	7.632	7.662	7.707	7.738	7.768	7.798	7.828	7.843	7.873	7.888	7.903
400	673	7.563	7.593	7.608	7.652	7.682	7.712	7.741	7.766	7.771	7.801	7.816	7.831

TABLE 3

VALUES OF ENTROPY FROM SATURATION POINT TO TEMPERATURE T_2 IN UNITS OF ENTROPY PER POUND OR KILOGRAM

Pressures		1 kg.	2 kg.	4 kg.	6 kg.	8 kg.	10 kg.	12 kg.	14 kg.	16 kg.	18 kg.	20 kg.	10 lb.	5 lb.	3 lb.
Sat.	Tem.	99	120	143	158	169	179	187	194	200	206	211	89.5	72.4	61
Sup.	Temp.														
deg.C	deg. F														
100	212	.0012	......	......	......	......	......	......	......	......	......	......	.0143	.0345	.0492
110	230	.0135	......	......	......	......	......	......	......	......	......	......			
120	248	.0254	......	......	......	......	......	......	......	......	......	......	.0382	.0581	.0727
130	266	0370	.0012	......	......	......	......	......	......	......	......	......			
140	284	.0484	.0237	......	......	......	......	......	......	......	......	......	.0609	0805	.0951
150	302	.0594	.0352	.0085	......	......	......	......	......	......	......	......			
160	320	.0701	.0463	.0204	.0025	......	......	......	......	......	......	......	.0825	.1019	.1164
170	338	.0807	.0571	.0319	.0149	.0013	......	......	......	......	......	......			
180	356	.0910	.0677	.0431	.0268	.0141	.0014	......	......	......	......	......	.1032	.1224	.1368
190	374	.1011	.0780	.0529	.0382	.0263	.0146	.0043	......	......	......	......			
200	392	.1110	.0881	.0643	.0492	.0380	.0271	.0187	.0087	......	......	......	.1229	.1420	.1564
210	410	.1207	.0980	.0755	.0599	.0491	.0388	.0317	.0221	.0148	.0065	......			
220	428	.1301	.1077	.0855	.0702	.0598	.0500	.0434	.0344	.0280	.0210	.0147	.1420	.1609	.1752
230	446	.1394	.1172	.0953	.0803	.0701	.0606	.0545	.0458	.0400	.0337	.0286			
240	464	.1486	.1265	.1049	.0900	.0801	.0708	.0649	.0566	.0511	.0453	.0408	.1604	.1791	.1934
250	482	.1576	.1356	.1142	.0996	.0898	.0806	.0749	.0667	.0616	.0560	.0520			
260	500	.1664	.1445	.1234	.1088	.0992	.0901	.0846	.0765	.0715	.0662	.0624	.1781	.1967	.2110
270	518	.1751	.1533	.1324	.1179	.1084	.0995	.0940	.0860	.0811	.0759	.0722			
280	536	.1837	.1620	.1412	.1269	.1174	.1085	.1032	.0952	.0904	.0853	.0816	.1953	.2138	.2280
290	554	.1921	.1705	.1499	.1356	.1262	.1175	.1121	.1042	.0995	.0944	.0908			
300	572	.2004	.1789	.1585	.1442	.1349	.1262	.1209	.1131	.1084	.1033	.0998	.2120	.2305	.2447
310	590	.2087	.1872	.1669	.1527	.1435	.1348	.1296	.1218	.1171	.1121	.1086			
320	608	.2168	.1954	.1752	.1611	.1519	.1433	.1381	.1303	.1257	.1207	.1172			
330	626	.2248	.2035	.1834	.1694	.1602	.1517	.1465	.1387	.1342	.1292	.1257			
340	644	.2328	.2115	.1915	.1775	.1685	.1599	.1548	.1471	.1425	.1376	.1341			
350	662	.2407	.2195	.1995	.1856	.1765	.1681	.1630	.1553	.1508	.1458	.1424			
360	680	.2485	.2273	.2074	.1936	.1846	.1761	.1711	.1634	.1589	.1540	.1506			
370	698	.2563	.2351	.2153	.2015	.1926	.1841	.1791	.1715	.1670	.1621	.1587			
380	716	.2640	.2429	.2231	.2093	.2005	.1920	.1871	.1794	.1750	.1700	.1667			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.2171	.2083	.1999	.1949	.1873	.1829	.1780	.1746			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]							

Sup. deg. C.	Temp. deg. F.											
100	212	0.8										
110	230	9.2										
120	248	17.5										
130	266	25.8	8.6									
140	284	34.1	17.2									
150	302	42.4	25.8	6.5								
160	320	50.7	34.4	15.7	2.0							
170	338	59.0	42.9	24.8	11.7	.8						
180	356	67.4	51.4	33.8	21.3	11.2	.9					
190	374	75.7	60.0	42.7	30.7	21.2	11.8	3.5				
200	392	84.0	68.5	51.6	40.0	31.0	22.3	14.9	7.4			
210	410	92.3	77.0	60.4	49.2	40.6	32.4	25.6	18.9	12.8	5.6	
220	428	100.6	85.5	69.2	58.3	50.0	42.2	35.9	29.7	24.3	18.3	12.9
230	446	109.0	94.0	78.0	67.3	59.2	51.7	45.8	40.0	35.0	29.7	25.3
240	464	117.3	102.5	86.7	76.2	68.3	61.0	55.3	49.8	45.2	40.3	36.6
250	482	125.7	111.0	95.4	85.0	77.3	70.2	64.7	59.3	55.0	50.4	46.9
260	500	134.1	119.5	104.1	93.9	86.3	79.2	73.9	68.6	64.4	60.0	56.8
270	518	142.5	128.0	112.8	102.7	95.2	88.3	83.0	77.8	73.7	69.4	66.3
280	536	151.0	136.5	121.5	111.5	104.1	97.2	92.0	86.9	82.9	78.7	75.6
290	554	159.4	145.1	130.2	120.3	113.0	106.2	101.0	96.0	92.0	87.8	84.8
300	572	168.0	153.7	138.9	129.1	121.8	115.1	110.0	105.1	101.1	96.9	94.0
310	590	176.5	162.3	147.7	137.9	130.7	124.1	119.0	114.1	110.2	106.0	103.1
320	608	185.1	171.0	156.5	146.8	139.7	133.0	128.0	123.1	119.3	115.2	112.3
330	626	193.8	179.7	165.3	155.7	148.6	142.0	137.1	132.2	128.4	124.3	121.4
340	644	202.5	188.6	174.1	164.6	157.6	151.1	146.2	141.3	137.5	133.5	130.6
350	662	211.3	197.3	183.1	173.6	166.6	160.2	155.3	150.5	146.7	142.7	139.8
360	680	220.2	206.2	192.0	182.6	175.7	169.3	164.4	159.7	155.9	151.9	149.1
370	698	229.1	215.2	201.1	191.7	184.9	178.5	173.6	168.9	165.2	161.2	158.4
380	716	238.1	224.2	210 2	200.8	194.0	187.7	182.9	178.2	174.5	170.5	167.8
390	734	247.2	233.3	219.3	210.1	203.3	197.0	192.2	187.5	183.9	179.9	177.2
400	752	256.3	242.5	228.6	219.3	212.6	206.3	201.6	196.9	193.3	189.3	186.6
Pressure		**14.2 lb**	**28.4 lb**	**56.8 lb**	**85.2 lb**	**113.6 lb**	**142.2 lb**	**170.4 lb**	**199.0 lb**	**227.2 lb**	**245.8 lb**	**284.4 lb**

axis in making this a diagram for the English system of units. To get the curves of entropy at points of pressures of an integral number of pounds, interpolation is resorted to, which is shown in Par. 13.

11 The entropy curves for the liquid and for saturated steam are then constructed using the entropy values for saturated steam and for the liquid as found from Peabody's Steam Tables. To these curves have been added the changes of entropy from the saturation point to the various temperatures for the purpose of finding the total entropy change to each temperature. A rapid method of finding the area to the temperature T_2 on the $\frac{C_p}{T}$ curves without resorting to integration with a planimeter is to use the mean height of the curves for each 10 degrees. This is legitimate as the curvature of the lines is very small. The values of the entropy change for the various pressures for a change from the point of saturation to the temperature T is shown in Table 3. This table is given for the purpose of showing values which may be laid off on any entropy diagram for saturated steam which differs from that derived from Peabody's tables.

12 The curves are laid off as shown in Fig. 4 and on it are placed lines of constant total heat which are of service in certain problems.

13 The lines for the pressures in kilograms are shown by faint lines. To find the lines for other pressures, lines were drawn in Fig. 5 in which the abscissae represented the entropy change from a given pressure line[1] on any line of constant temperature and the ordinates represented the pressure corresponding to that change. In this manner lines were drawn for 750 deg. fahr. to 300 deg. fahr. at intervals of 50 deg. fahr. If now a horizontal line were drawn at any pressure in pounds per square inch the intersepts by these curves would give the change in entropy from one line of pressure to the desired curved constant pressure line at the different temperatures. From these values the curves of constant pressures for integral pounds per inch were drawn.

14 In the same manner lines for 10 pounds per square inch, 5 pounds per square inch, and 3 pounds per square inch were constructed in Fig. 3. From these the values of $\frac{C_p}{T}$ were measured and these gave the corresponding entropy lines in Fig. 4. The curves in Fig. 3 were completed by finding the value of C_p at the point of saturation by the formula of Knoblauch and Jakob.

[1] The particular pressure line from which measurements are made is shown by the pressure at which the various curves cut the radial axis.

$$(C_p)_{Sat} = 0.41 + \frac{2.52 \times 10^8}{(T_k - T_s)^4} \qquad [6]$$

(T_k = 638 deg. cent. absolute = Critical temp.)

m it determining the end point of the curve.

The values of the heats added from the saturation point to ious temperatures of superheat for the various pressures were rom the lines of specific heat by the method used in finding the ', and are given in Table 4. To these are added the total heat team at saturation to find the total heat necessary to change a of water at the freezing point into steam at the superheated vhen the pressure is kept constant. The heats at different atures were plotted and from these the temperatures corre-ıg to definite heats were found for the purpose of plotting the constant heat.

The curves of total heat against temperature show first of all e heats of saturation lie on a straight line according to the ı for total heat. The lines for different pressures show consider-ıriation from each other at these points. As the lines are into the superheated region they approach each other so that mperature of 750 deg. fahr. a variation of pressure from 280 pounds is produced by an addition of 9½ heat units. This hat in the superheated region the total heat varies little with ssure. As the temperature increases the superheated steam s more nearly a gas.

I wish to acknowledge my indebtedness to Mr. E. A. Fessenden University of Missouri for his assistance in drawing the plates aiding me in this work.

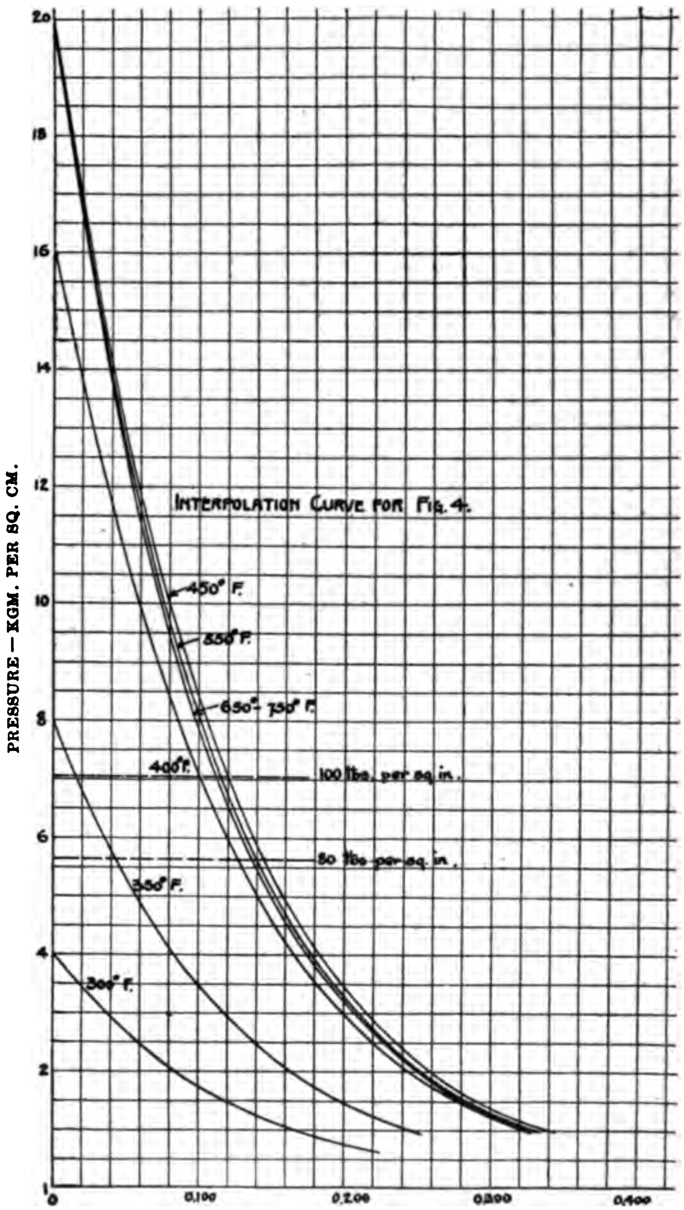

FIG. 5 CURVES FOR INTERPOLATION

No. 1153

THE COLE LOCOMOTIVE SUPERHEATER

NOTES CONCERNING THE PERFORMANCE OF THE COLE SUPERHEATER AS APPLIED TO THE PURDUE UNIVERSITY LOCOMOTIVE, "SCHNECTADY NO. 3"

BY PROF. W. F. M. GOSS, LAFAYETTE, IND.
Member of the Society

The experimental locomotive of Purdue University (Schenectady No. 2) which was originally designed to supply and to operate upon saturated steam, has recently been equipped with a Cole superheater and has since been known as Schenectady No. 3.

2 The Cole superheater, as applied to this locomotive consists chiefly of a series of return tubes extending inside of certain of the flues which make up a portion of the direct heating surface. To make room for the superheater the upper central portion of the usual flue space is taken by sixteen 5 inch flues, which are reduced to a diameter of 4 inches for 7 inches of their length at the fire-box end, and increased to a diameter of $5\frac{1}{16}$ inches at the front tube sheet. They have a length between flue sheets of 138 inches. In each of these sixteen flues there is an upper and a lower line of superheating tubes. Each line extends from a steam pipe header in the smoke-box back into its flue to a point near the back tube sheet, where it meets and is screwed into a return fitting of special design. From the second of the two openings in this fitting, a similar pipe extends forward through the flue and into the smoke-box to a second header, from which branch pipes lead to the cylinders. Altogether there are 32 of these loops. In 13 of the flues. the lower loops are $116\frac{3}{8}$ inches long, extending into the flue within 2 feet 5 inches of the back tube sheet. In the other three flues, the loops are, respectively, 3 feet, 2 feet, and 1 foot shorter than the normal. The upper loop in each flue is in all cases approximately 9 inches shorter than the

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lower loop. The headers to which the pipes of the superheater c nect at the smoke-box end are of cast steel. They have walls ⅜ in thick and are cored in such a manner that all steam passing throttle of the locomotive must pass some one of the several loc

3 The following dimensions and constants will be of interest

HEATING SURFACE OF BOILER AS DESIGNED FOR SUPPLYING SATURATED ST PRIOR TO THE TIME WHEN IT WAS FITTED WITH A SUPERHEATER

Number of 2 inch flues	200
Length of flues, feet	11.47
Heating surface in flues, fire side, square feet	1086
Heating surface in fire-box, square feet	126
Total heating surface, square feet	1212

HEATING AND SUPERHEATING OF BOILER AS NOW EQUIPPED WITH THE C SUPERHEATER

Number of 2 inch flues	111
Number of 5 inch flues	16
Length of flues, feet	11.47
Heating surfaces in flues, fireside, square feet	817
Heating surface in fire box, square feet	126
Total water heating surface, square feet	943
Outside diameter of superheater tubes, inches	1¼
Number of loops	32
Average length of pipe per loop, feet	17.27
Total superheating surface based upon outside surface of tubes only (surface of headers neglected), square feet,	193
Total heating and superheating surface, square feet	1136

CHANGES IN EXTENT OF HEAT TRANSMITTING SURFACE RESULTING FROM ADDITION OF SUPERHEATER

2 in. tubes displaced to make room for superheater:	
Number	89
Per cent of original number	44
Direct heating surface displaced to make room for superheater:	
Square feet	269
Per cent of original area	22
Heat transmitting surface lost by the change as shown by comparing the original heating surface with the sum of direct and superheating surface of the reconstructed boiler:	
Square feet	76
Per cent of original surface	6
Ratio of the superheating surface to direct heating surface in the reconstructed boiler	0.2

4 For the purpose of observing performance, thermometers re ing 750 degrees fahr. were inserted in each of the two branch pi extending between the superheater and cylinders, in the discha

side of all loops, six in number, the length of which varied from the normal, and in the upper loop of the right hand upper flue, which loop is of normal length. All thermometers were in wells thoroughly jacketed by a current of steam flowing from the stream, the temperature of which was sought.

5 The results show that the degree of superheat in the steam delivered to cylinders is largely affected by the rate of evaporation. Thus in Fig. 1 the average degree of superheat as shown by readings taken from the two branch pipes is plotted against the rate of evaporation. It shows that as the evaporation per square foot of heating surface per hour is increased from 7 pounds to 15 pounds, the degree

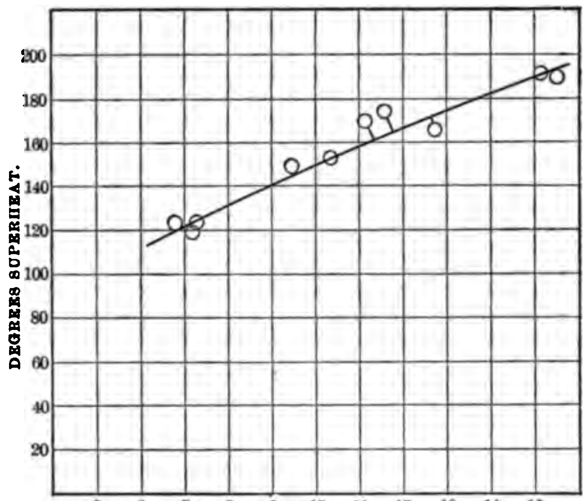

FIG. 1

of superheat rises from 122 to 188 degrees fahr. For all tests represented upon this diagram each pound of steam delivered received from the direct heating surface approximately 1160 B.t.u. and from the superheating surface from 70 to 104 B.t.u. depending upon the rate of power at which the boiler was worked. This fact is of especial interest when it is remembered that the extent of superheating surface is one-fifth that of the direct heating surface.

6 Another expression of the fact to which attention has already been called is well set forth by Fig. 2, which shows the per cent of the total heat taken up by the water and steam which is absorbed by the superheater, plotted in terms of smoke-box temperature. It will be

seen that as the temperature of the smoke-box changes from 600 deg. fahr. to 800 deg. fahr., the heat absorbed by the superheater rises from 5.6 per cent to 8.5 per cent of the total taken up by the water and steam.

7 The degree of superheating obtained from loops of different lengths is shown graphically by Fig. 3. It will be seen that the amount of superheating obtained increases rapidly as the loop is increased in length. This results from the fact that each increment in the length of the loop carries the superheating element nearer the fire-box and

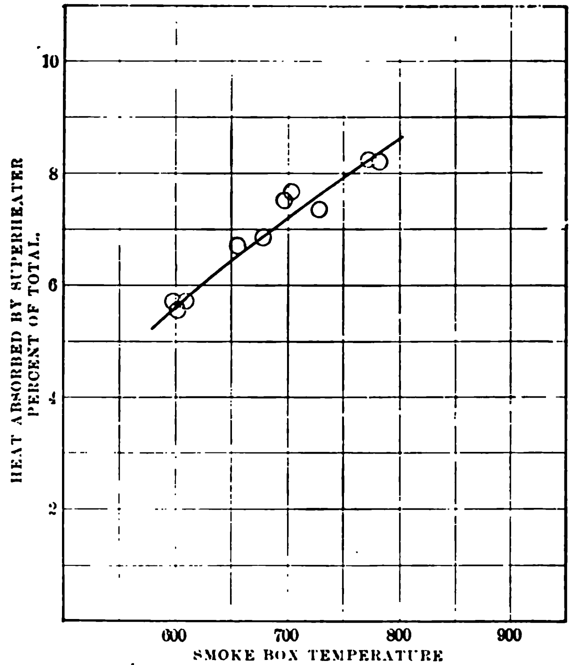

FIG. 2

serves to increase the average temperature to which the whole loop is exposed. The effect therefore is twofold; first, that resulting from an increase of superheating surface, and second, that resulting from an exposure of that surface to a higher average temperature. The basis for these observations (Fig. 3) was supplied by the superheating loops arranged in three flues making up a portion of the left hand vertical row. The lower loops in those flues were, respectively, 80 inches, 92 inches and 105 inches, while the upper loops were, respectively, 71 inches, 84 inches and 96 inches. A review of the plotted points at once discloses the fact that a higher degree of superheating is obtained from the lower loop of a given length than is possible from an upper loop of the same or even greater length. Comparing results as obtained, it appears that the lower loop in a given flue, while but a few inches longer than the upper loop, gives from 25 to 30 per cent more superheating effect. This probably is to be accepted as a measure of the advantages which come to that element of the superheating surface which is first to receive the flow of the current of moving gases, though it is not impossible that the lower loop may claim some advantages from its position in the flue.

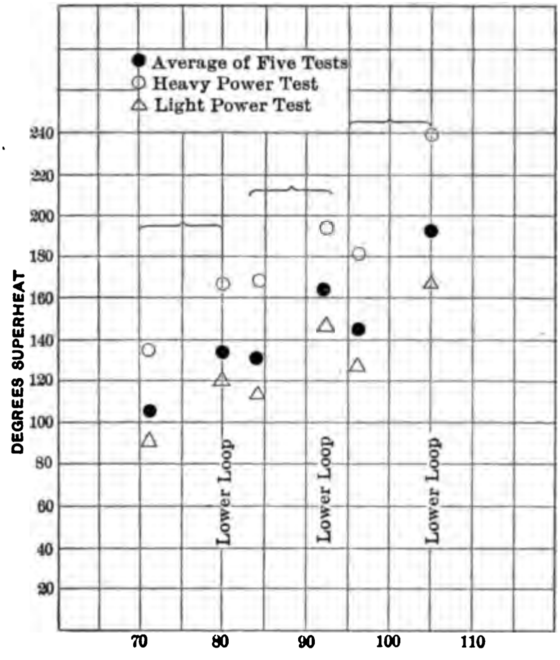

FIG. 3

8 It has been observed that the average temperature of the steam in the two branch pipes is always less than the calculated temperature, assuming all superheating loops to give the same performance as those which are under observation. A reason for this must be found in the difference in the volume or quality of the furnace gases transmitted by the several flues.

CYLINDER PERFORMANCE

9 While a full analysis of the cylinder performance of the locomotive must be reserved for another time, it is proper here to note that when served with saturated steam (locomotive "Schenectady No. 2"), its performance under normal condition of running was represented by a range of from 24 to 27 pounds of steam per indicated horse power hour. After being equipped with a superheater, substantially the same locomotive ("Schenectady No. 3") delivers under ordinary conditions of running an indicated horse power upon the consumption of from 20 to 22 pounds of superheated steam per hour, a difference of about 17 per cent. The saving of coal, however, is far less than that of steam, the average for a considerable number of tests being between 6 and 7 per cent.

10 The writer acknowledges indebtedness to Mr. L. E. Endsley in charge of the locomotive laboratory of Purdue University, under whose immediate direction all tests have been run.

DISCUSSION

Mr. Francis J. Cole In any form of superheater, the best results are obtained by causing the saturated steam to flow in an opposite direction to the flue gases, so that the steam will receive its initial superheat at the point farthest removed from the furnace and consequently at the lowest temperature, and traveling thence to the point of highest temperature nearest to the furnace, and from there being conveyed to the cylinders without transfer of heat. In this way there would be a difference of 200 to 300 deg. or more of heat at all times between the saturated steam and the flue gases.

2 In the ordinary forms of locomotive superheaters, in which the loops are placed inside of large tubes (usually 5 inches outside diameter), these conditions are met in the first leg of the loop, but in returning to the front of the boiler the condition is reversed and the direction of flow of the steam is the same as that of the gases; consequently just before the steam passes into the steam pipes and thence to the cylinders, there is not sufficient difference of temperature between it and the gases to absorb the greatest amount of heat.

3 There are practical difficulties in the way of improving this condition and it is probable that superheaters of the usual construction, which include the Schmidt, the Vaughan-Horsey and the one under consideration, represent the best compromise that can be made.

4 While many road tests have been made to determine the economy of superheated steam, the writer knows of none made with the degree of refinement and the large number of temperature observations at the different parts of the apparatus represented in those made by Dr. Goss.

5 It is interesting to note the difference in the amount of heat absorbed by the steam in passing through the upper and lower loops, showing that even when of the same length, the superheating surface is less efficient in the upper than in the lower loop. This suggests the idea that by placing the return bends vertically, and allowing the saturated steam to flow first into the upper pipe, that the conditions would be improved, as it would flow forward when exposed to the highest temperature. This would more nearly comply with the theoretical conditions.

6 It has been customary recently in road tests to take the temperature readings of the superheated steam at the cylinders, placing the thermometers directly in the steam chest, or, in the case of piston valves with inside admission, in the upper part of the central cavity of the valve chest, where the live steam flows in on its way through the ports to the cylinders. The temperature readings of the report under discussion were made in the steam pipes, and the probable difference in temperature of the readings taken there and in the cylinder would be approximately 25 to 30 deg.

7 Regarding the difference in temperature of the steam in the three groups of pipes which were purposely shortened, it seems to be a question of length, although it would be fair to suppose that when the loop was nearer the fire box the temperature would be higher in a greater degree than proportionately to the length. However, an examination of Fig. 3 shows that 10 in. difference in length makes a difference of 27 deg. or about 20 per cent, the steam apparently receiving 1.7 degrees of superheat for each inch in length for tubes 80 in. long, 1.77 for tubes 92 in. long, and 1.81 for tubes 105 in. long.

8 There is a practical limit, however, to the length of these flues, which in the present instance were normally 29 in. from the back tube sheet. This is probably as near the furnace as they could be carried without danger of burning or blistering the ends. It seems necessary to locate them some distance away from the direct action of the flames, so that the temperature of the flue gases will be considerably lowered before coming in direct contact with the superheater tubes.

Mr. Henry H. Vaughan The arrangement of the superheater in the locomotive Schenectady No. 3 employs a rather greater number of 5 in.-flues than has been generally used on the Canadian Pacific. On their engines 378 2 in.-flues in an ordinary engine, have been changed to 248 2 in.-flues and 22 5 in.-flues on a superheater engine, or 36½ per cent of the 2 in.-flues have been replaced by 5 in.-flues. In the Schenectady engine 44½ per cent have been replaced, and the arrangment has evidently not worked out quite as well as with the Canadian Pacific, where 5.9 2-inch flues are the equivalent of one 5-in., whereas on the Purdue locomotive one 5-in. takes the place 6.9 2-in. tubes, and there is therefore a slightly greater loss in evaporating surface. On some engines, however, the Canadian Pacific has used 24 5 in.-flues in place of 22 with the same size shell, so that the Purdue locomotive is between the limits thus far successfully used in locomotive practice.

2 The results given by Professor Goss as to the amount of superheat in the tubes of different lengths are exceedingly interesting. It is, however, of importance to know the location of the tubes in the boilers in which the temperature was measured. It is quite probable that the amount of superheat coming from two tubes of the same length varies according to their position, as the tubes nearer the top might carry a much larger proportion of the steam flowing through the superheater than those at the bottom. In other words the steam might be short circuited through the upper tubes, and as the amount of superheat will vary more or less inversely as the rate of flow of steam through the different tubes, a higher degree of superheat would be expected through the tubes farthest from the header, or at any rate, through the tubes through which the smallest flow of steam takes place, although it would be difficult to state whether they would or would not be those closest to the header.

3 There is also a possibility of a difference in the amount of superheating as the distribution of the draft is changed. It has been found that a considerable difference can be made where brick arches are employed, as by the adjustment of this arch more or less heat may be thrown through the upper tubes.

Mr. August H. Kruesi The manufacturers of turbines have never been backward in offering data upon this subject. A rough approximate statement would be that the steam consumption would be reduced 1 per cent for each 12½ per cent of superheat, depending somewhat on the amount of superheat. For example, 200 deg. superheat would probably change the consumption 1 per cent for every 14 deg., whereas 75 deg. superheat would probably change the consumption 1 per cent for every 11 deg. In other words, a moderate amount of superheat gives a relatively larger improvement per unit of superheat.

2 Manufacturers of boilers, so far as I have been able to learn, have been backward in giving out information as to the amount of coal required for a given amount of superheat in combined superheater boilers. We have, therefore, had to depend for such information on those not directly interested in either kind of apparatus.

3 I endeavored to give one or two definite test results relating to plant economy, in my discussion of Mr. Barrus' paper and I stated that in a particular test, with combined superheaters, 200 deg. superheat showed no substantial gain in coal consumption. The point I want to bring out now is that I do not mean by this that superheat in general is not desirable. In fact, I consider it very desirable, not only as regards fuel economy, but for several other reasons.

4 I stated my opinion, that with small size turbines, if the capacity of the plant is not considered to be great enough to justify the employment of high grade engineers, the use of superheat will not be warranted; not because it is not economical, but because its employment requires close and intelligent attention on the part of the operators, and as I have the operating difficulties in mind (and not because of any doubt as to the ability of high superheat to effect a reduction in coal consumption), I recommended a moderate amount of superheat. A number of considerations aside from economy must control the decision on this point. I believe 75 deg. at the turbine or, roughly, 100 deg. at the boiler, will justify its use as far as economy is concerned, by effecting 3 or 4 per cent improvement anyway; for larger plants about 125 deg. may be used. It might be well to go higher, but anything above this figure is open to question.

No. 1154

EXPERIENCES WITH SUPERHEATED STEAM

By GEO. H. BARRUS, BOSTON, MASS.
Member of the Society

PLANT A

My experiences with superheated steam date back to 1874. They began at the Massachusetts Institute of Technology in connection with the "Dixwell" experiments. The plant on which these experiments were made consisted of an ordinary 36-inch vertical fire box boiler set in brick work and provided with a Dutch-oven furnace, a rectangular cast iron superheater set over an independent furnace, and an 8 in. by 24 in. non condensing Corliss engine.

2 The superheater here proved unreliable. It cracked after a short time, and was abandoned. Later the vertical boiler was found to answer every purpose by simply carrying the water to a low point, and exposing considerable steam heating surface to the action of the products of combustion. The temperature of the steam was regulated by the activity of the fire. This apparatus proved to be a most satisfactory form of superheater. With it there was no difficulty in maintaining a temperature of 600 degrees fahr. and superheating all the steam that was required by the 8 in. by 24 in. engine.

3 The object of the Dixwell experiments was to show that the degree of superheating necessary to prevent cylinder condensation varied in direct proportion to the ratio of expansion. On the engine in question, with a ratio of expansion of 3 to 2, the number of degrees required was about 110; with a ratio of 2½ to 1, the number was increased to 146 degrees, and with a ratio of 4 to 1, it was still further increased to 190 degrees. As a telltale, indicating when the condensation in the cylinder was suppressed, a cylinder pyrometer, which was similar in outward appearance to any metallic pyrometer, was inserted through the wall of the cylinder in such a position as to lie diametrically across the cylinder just beyond the counter-bore, and a cavity was cut in the inside face of the cylinder head to make room for it. The action of this instrument proved an interesting and

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2 The superheater here proved unreliable. It cracked after a short time, and was abandoned. Later the vertical boiler was found to answer every purpose by simply carrying the water to a low point, and exposing considerable steam heating surface to the action of the products of combustion. The temperature of the steam was regulated by the activity of the fire. This apparatus proved to be a most satisfactory form of superheater. With it there was no difficulty in maintaining a temperature of 600 degrees fahr. and superheating all the steam that was required by the 8 in. by 24 in. engine.

3 The object of the Dixwell experiments was to show that the degree of superheating necessary to prevent cylinder condensation varied in direct proportion to the ratio of expansion. On the engine in question, with a ratio of expansion of 3 to 2, the number of degrees required was about 110; with a ratio of 2½ to 1, the number was increased to 146 degrees, and with a ratio of 4 to 1, it was still further increased to 190 degrees. As a telltale, indicating when the condensation in the cylinder was suppressed, a cylinder pyrometer, which was similar in outward appearance to any metallic pyrometer, was inserted through the wall of the cylinder in such a position as to lie diametrically across the cylinder just beyond the counter-bore, and a cavity was cut in the inside face of the cylinder head to make room for it. The action of this instrument proved an interesting and

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No. 1154

EXPERIENCES WITH SUPERHEATED STEAM

By GEO. H. BARRUS, BOSTON, MASS.
Member of the Society

PLANT A

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important feature of the work. When the engine was running with ordinary saturated steam, the pyrometer responded to the variations of temperature in the cylinder, and during every revolution the index hand vibrated over a range of 20 to 25 degrees of temperature. It jumped to the highest point at the beginning of the stroke when the steam was admitted, and then fell off to the lowest point during expansion and exhaust. When the steam began to be superheated, the range of vibration began to diminish, and when the temperature rose to a sufficient degree, the vibrations disappeared altogether, and the pyrometer indicated a constant temperature. The latter was slightly above the normal for the initial pressure. It is thus seen that with the 4 to 1 ratio of expansion and 190 degrees superheat at the throttle valve, there was a very large drop in temperature in the short distance between the throttle valve and the interior of the cylinder, that distance being not more than two linear feet.

4 In connection with this work, an interesting experiment was made to demonstrate to what extent the drop in temperature between the throttle valve and the cylinder was due to heat converted into work. The engine was stopped, and the four valves set wide open. Then the throttle valve was adjusted to such an opening as to discharge steam at the same rate as was consumed when the engine was running. With a ratio of expansion of 2½ to 1 and a temperature of 450 degrees at the throttle valve, the cylinder temperature was 70 degrees lower and the exhaust pipe temperature 140 degrees lower when the engine was running than when the steam was blowing through. In another case with a ratio of 3 to 2 and 410 degrees temperature at the throttle, the cylinder temperature was 45 degrees lower and the exhaust temperature 120 degrees lower with the engine running than with the steam blowing through. A comparatively small portion of the drop in temperature was therefore due to radiation losses, and a large portion to the conversion of heat into work.

PLANT B

5 The next experience was with a superheater of the Bulkley type, set over an independent furnace, and surmounted by a coil of wrought iron pipes. The area of exterior surface in the main superheater, which consisted of two "U" sections, was some 60 square feet, and that in the added pipes about 60 feet more, making a total of about 120 square feet. The area of grate surface was 7 square feet. This apparatus readily heated the steam made by an 80 horse power boiler, which was 75 feet away, to any temperature desired. On a

test it was found that one pound of anthracite coal, containing 15 per cent of ash and refuse, superheated 50 pounds of steam 228 degrees, besides evaporating the moisture due to condensation in the steam pipe, and whatever moisture came over from the boiler. The steam pressure was 75 pounds.

PLANT C

6 Another experience with a superheater of the Bulkley type was a case where the attachment was made to a horizontal return tubular boiler. The boiler was one of a plant of two, the shells of which were 48 in. in diameter and 16 ft. long, used in running a 16 in. by 36 in. non-condensing four-valve engine. In this engine the steam valves were of the double poppet type, and the exhaust valves, plain slide valves. All the steam passed through the superheater. A test was made before and after the installation. The consumption of small anthracite coal before the application was 4.4 pounds per indicated horse power per hour. When the superheater was applied, the temperature was raised 66 degrees and the coal consumption was reduced to 4.1 pounds per indicated horse power, the saving being about 6 per cent. The superheating in this case was not sufficient to wholly prevent condensation. A cylinder pyrometer which showed a vibration of 48 degrees with saturated steam, still gave 22 degrees with the limited superheating.

7 The superheater in this case was located behind the bridge wall in the manner usually followed for this type of boiler, and the only heat to which it was exposed was that radiated downward from the products of combustion passing under the boiler shell. With a view to increasing the degree of superheating, an independent furnace was built under the superheating pipes, having fire and ash doors placed in the side wall. The grate had an area of 7 square feet. By burning 5½ pounds of coal per square foot of grate per hour the superheating was increased to 165 degrees, and the vibrations of the pyrometer were reduced to 17 degrees. Under these circumstances, a test with the superheater shut off gave a consumption of 4.21 pounds of small anthracite coal per indicated horse power per hour, and with the superheater running under the conditions noted, 4.04 pounds. The saving was 4 per cent. The decrease in evaporation per pound of coal due to the superheater was 10.2 per cent.

PLANT D

8 Still another experience was with a Bulkley superheater, this one being arranged in three sections, and set in an independent

furnace. The heating surface was about 90 square feet, and the grate surface about 6 square feet. It was arranged for superheating the steam used by a 21 in.and 42 in. by 48 in. compound Wolff engine. This engine had slide valves for initial steam and final exhaust, and cylindrical valves, similar to the Corliss, for the exhaust of the high pressure cylinder, which served also as the admission valves of the low pressure cylinder. The vacuum was produced by an independent steam-driven air pump and condenser 12 in. by 16 in. by 18 in. The superheater was placed near the engine. The boilers, which were 250 feet away, were of the horizontal return tubular type. No provision was made for draining the steam pipe, and all the water condensed in the pipe, or brought over from the boilers, was reëvaporated by the superheater. The plant ran 10¾ hours per day, and, at the end of the day, the fires in both the boilers and superheater were allowed to burn out, being started again with wood in the morning. A test was made using anthracite coal, broken sizes. The engine developed 425 indicated horse power, and used about 8700 pounds of feed water per hour, or 20.5 pounds per indicated horse power per hour. The coal used in the superheater for the day's run of 10¾ hours was 277 pounds, or only 2 per cent as much as the coal used in the boilers. This amounted to 13,815 pounds and the total coal was at the rate of 3.02 pounds per indicated horse power per hour. It was found that the temperature of the steam coming out of the superheater was no greater than that going into it; in fact, it was a little less, showing that the only benefit derived was the reëvaporation of the water contained in the steam.

PLANT E

9 The next experience was with superheated steam generated by vertical tubular boilers of the Corliss rolling-pin type. Two of these were used for supplying a 23 in. by 60 in. single cylinder Corliss non-condensing engine. The area of grate surface in each was 45 square feet; water heating surface in each, 940 square feet; and steam heating surface, 425 square feet. 90 degrees of superheat were produced with a flue temperature of 480 degrees and a rate of combustion of 11 pounds of anthracite broken coal per square foot of grate per hour. A test of the engine was made when using steam derived partly from the two boilers mentioned, and partly from a horizontal return tubular boiler producing saturated steam, the vertical boilers doing so much of the work, however, that the steam was still superheated 82 degrees. The consumption of feed water was 26.8 pounds per indicated horse power per hour. When the horizontal boiler was crowded to supply most

of the steam, and the vertical boilers supplied so little that the superheating disappeared, the consumption of feed water was increased to 29.3 pounds per indicated horse power per hour. The difference in these figures is about 9 per cent. The difference in the evaporative performance of the boilers was so much greater in favor of the horizontal boiler, that the consumpton of coal was in both cases about the same.

10 In this connection, it may be added that, in the case of four other simple engines which the writer tested, where the amount of superheating ranged from 25 to 59 degrees, with an average of 34 degrees, there was a reduction in the percentage of cylinder condensation and leakage, as compared with that found in engines using ordinary steam under similar conditions, amounting to 8 per cent.

PLANT F

11 The next experience was with a plant of five 64-inch vertical boilers of the Corliss "Centennial" type, having 3 inch tubes 14 feet in length, each boiler having 951 square feet of heating surface, of which 317 square feet was steam heating surface. These boilers superheated the steam 75 degrees. They supplied a 28 in. by 48 in. single cylinder non-condensing Corliss engine through a 12 inch pipe, 270 feet in length. The drop in temperature between the boilers and the throttle valve when the engine indicated 410 horse power was 49 degrees, so that at the engine the superheating was only 26 degrees.

12 The chief interest in this plant lay in the effect of the hot steam and hot gases on the long fire tubes. It was found on a feed water test of the plant that the engine consumed 31 pounds of steam per indicated horse power per hour, and on a leakage test the output of the boilers appeared to be at the rate of about 1500 pounds of steam per hour, or nearly 4 pounds of steam per indicated horse power per hour. The leakage was traced to the upper tube sheets where a large number of the tube ends were blowing steam. Re-rolling of these tubes overcame the leakage to a considerable extent, but did not altogether prevent it.

13 In the other vertical boilers which have been referred to, where there was an equal amount of superheating without difficulty of this kind, the length of tubes was 10 feet or less, and they were of smaller diameter.

PLANT G

14 The next experience was with an independently fired superheater of somewhat larger proportions than any thus far referred to.

The heating surface here was made up of 2-inch continuous wrought iron pipes which presented a total area of 2640 square feet, and the grate surface measured 32 square feet. The brick setting measured 16 feet long, 9.5 feet wide and 22.5 feet high, over all. Steam was supplied from a plant of Babcock & Wilcox horizontal water tube boilers containing 10,500 square feet of heating surface and 178 square feet of grate surface.

15 A 10-hour test was made with this superheater delivering steam at a temperature of 697 deg. fahr. The boiler pressure was 149 pounds, giving a superheating of 337 deg. fahr. The weight of steam passed through was 25,982 pounds per hour. The weight of dry coal consumed was 535 pounds per hour, and this had 8 per cent ash and refuse. The calorific value of the fuel was 15,271 B.t.u. per pound of combustible. Reducing these quantities to the unit rate, one pound of dry coal superheated 49 pounds of steam 337 degrees, besides evaporating whatever moisture was carried over from the boilers and condensed in the connecting pipes. It is probable that the percentage of moisture, all told, which entered with the steam was between 1 and 2 per cent.

16 A noteworthy incident of this test was the effect of the highly heated steam on the joints of the piping and on the packings and gaskets of the valves. Whenever the steam came in contact with fibrous material or rubber, these were completely burned out, and the joints or valve stems set to profuse leaking. The flange joints in the piping, which were of the Van Stone type with corrugated copper gaskets, were injured to some extent and many of them set to leaking. The plant had previously been run at a temperature not over 550 degrees. Under this temperature there was no leaking at any point.

PLANT H

17 Another case of an independent superheater similar to that of the preceding plant is of interest. This was one which was used in a factory running ten hours per day, and during the remaining fourteen hours the superheater was out of active service, and the fire was banked. This superheater had 1810 square feet of heating surface and 32 square feet of grate surface. The boilers were of the horizontal water tube type.

18 A test was made covering the entire working period of twenty-four hours, and under the regular working conditions. The weight of dry New River coal consumed in the superheater was 3092 pounds, and it contained 7.9 per cent of ash and refuse. The weight of water

evaporated and passing through the superheater was 152,114 pounds. The number of degrees of superheating during the ten hours running time averaged 303 degrees, and the pressure was 136 pounds. The boiler horse power developed during running time was 389. Reducing these figures to the unit rate, one pound of dry coal superheated 49 pounds of steam 303 degrees, besides evaporating the moisture in the steam supplied by the boilers. The steam probably contained 1 per cent of moisture.

19 A Corliss compound condensing engine to which the steam from this superheater was supplied was found to consume 9.8 pounds of steam per indicated horse power per hour when the superheating at the throttle valve was 300 degrees.

PLANT I

20 I will refer finally to a case of superheated steam furnished by a combined water tube boiler and superheater, embracing comparative tests between such a boiler and a straight boiler of the same size and type. The grate surface was of the same area in both. The heating surface in the straight boiler had an area of 2797 square feet and this was all water heating surface. In the superheating boiler the water heating surface was 2571 square feet and the steam heating surface 595 square feet. Total, 3166 square feet.

21 The tests were made with semi-bituminous coal at, or near, the rated capacity of the respective boilers. The steam from the straight boiler contained 3/10 of 1 per cent of moisture. That from the superheating boiler was superheated 216 degrees, with a pressure of 145 pounds.

22 Making allowance for the heat represented by the superheating on the assumption that the specific heat is 0.48, the efficiency of the two outfits came out precisely the same, viz: 75 per cent of the calorific value of the fuel.

DISCUSSION

Mr. August H. Kruesi In the last paragraph, Mr. Barrus gives some facts about the efficiency of a certain boiler with a combined superheater and without a superheater. The statement is made that the efficiencies are about the same. From this it would appear that a given amount of coal would generate about 9 per cent more steam in the simple boiler; but on the other hand, a turbine employing this amount of superheat would give about 15 per cent greater output, from which it appears that there would be a substantial coal economy in employing the boiler with combined superheater in connection with a turbine. On the other hand, the writer is familiar with tests made about two years ago on boilers of somewhat larger size, with combined superheaters, the superheaters in one test being flooded, and in the other test generating about 200 deg. superheat, the latter test showing a coal consumption per pound of steam about 14.7 per cent higher than the former test. The turbines in the latter case required about 15 per cent less steam per unit of output so that with this comparatively high superheat no material gain in coal economy was realized.

2 I hope Mr. Barrus will give us further data regarding the last test he describes—there being very little information on the subject which is available and which is comparable. Conclusions should be based on tests with the same boiler, tested when generating saturated and superheated steam, respectively.

3 I believe, after considerable observation in new plants in which turbines have been installed, that 125 deg. to 150 deg. superheat at the boiler is about as much as can be used with satisfaction under present conditions. Further tests may demonstrate the economy and desirability of using higher superheat: but my present belief as to the most desirable figures is to use no superheat for turbines up to 1000 kw. capacity; 75 to 100 deg. at the turbine for 2000 to 3000 kw. capacity; and 100 to 125 deg. at the turbine for 5000 to 8000 kw. capacity.

Mr. E. H. Foster In Mr. Barrus' paper he states that a pipe line at 550 deg. temperature gave no difficulties with the joints, whereas, at a high temperature (697 deg.) they had a great deal of leakage at the joints. I have also found that at a temperature of 500 deg., or at most 550 deg., there is very little likelihood of difficulty from the average pipe line which is designed for a steam pressure of 150 lb.

2 I have noticed a very interesting thing in connection with steam pipe lines when superheated steam is put in them. Frequently a pipe line will leak with saturated steam, but will not leak with superheated steam. I have again turned saturated steam into a pipe line, after using it for superheated steam, and found that the leakage returned. My theory to account for this is that the superheated steam maintains a more uniform temperature throughout the pipe line, holding the top and the bottom of the line at practically the same temperature, whereas, with saturated steam the moisture may run along the bottom of the line and keep the bottom cooler than

the top, causing a contraction of the lower side of the pipe and opening up the joints at the bottom enough to produce a leakage. I have always noticed that a steam pipe line, unless under very great external strain, will leak at the bottom of the joints.

3 Mr. Kruesi has spoken of its being practically not worth while for the sake of fuel economy alone to use superheated steam in installations of small power. He refers to steam turbine work, but I think we ought not to confine a discussion of superheated steam or the advantages of using it, to one of its uses alone.

4 In other words, let us consider other forms of engines than steam turbines. Any one who has had experience with small plants will agree that it is very much worth while to use superheated steam in small power plants. I have had an opportunity to observe the saving in introducing superheated steam in plants of from a hundred to two hundred horse power capacity, using pumping engines, electric light engines and industrial engines of various sorts—and the saving by the introduction of superheated steam is often very remarkable. I have scarcely had a report of a test where the saving was less than 10 per cent, by the introduction of superheat of about 125 deg. fahr. I have frequently had authentic reports of savings of 20 to 25 per cent, resulting entirely from the introduction of from 150 to 200 deg. superheat. Such figures are as readily obtained on plants carrying moderate steam pressures of 80 to 100 lb. per sq. in. as on those using much higher pressures. These facts have arisen so frequently that they ought to be considered in deciding whether superheated steam is worth while for small plants, or not.

5 I have one conspicuous case in mind, a certain steel plate mill in this country where steam is supplied by five 72 in. by 18 ft. H.R.T. boilers, tested at 150 h.p., each carrying 95 lb. steam pressure, burning Pittsburg coal, and driving a 34 in. by 48 in. non-condensing Corliss engine running at 54 r.p.m., driving six sheet mills, the steam line being about 80 ft. long. Steam is also used to drive a number of small water and feed pumps and four small automatic engines, simple non-condensing and also to heat buildings. The boilers were equipped with superheaters to give 150 deg. superheat, no other change being made in the plant. Coal consumption per gross ton of finished product for steam purposes at the works has averaged over 15.26 per cent less for the four months since the superheaters were installed, as compared with the previous yearly average.

6 In another large steel works where six 250 h.p. water tubular boilers are used to drive a power plant consisting of the following:

4—19 in. and 31 in. by 22 in. vertical cross compound automatic cut-off condensing engines, each direct connected to 1-300 kw. d.c. generator;
3—DeLaval single stage turbines each geared to two 100 kw. DeLaval d.c. generators;
2—14 in. and 24 in. by 14 in. Westinghouse single acting compound automatic cut-off non-condensing engines, belted to generators:

Superheaters were installed to give a superheat of 150 deg. In this case the steam pressure was 125 lb., and blast furnace gas and coal were used for fuel.

7 The steam pipe consisted of a 12 in. line 150 ft. long, only partially covered. Careful tests were made after superheaters were installed, with the intent of establishing a comparison between saturated and superheated steam. For the saturated steam run, water pumped from barrels on scales was sprayed into the steam pipe to neutralize the superheat. As a matter of fact there were a few degrees of superheat left in the steam, ranging from 0 deg. to 13 deg. at the various engines so that the test is really a comparison between steam with an average of about 8 deg. of superheat at the engine and steam with an average of about 120 deg. at the engine. The water rate obtained on the engines showed an advantage of 16.8 per cent in favor of the superheated conditions. Since blast furnace gas was largely used to fire these boilers, no accurate measure of fuel consumption was possible, but in my opinion little, if any, extra fuel is required in a combination of boiler and superheater of this sort to give a superheat of about 100 deg.

Mr. Max E. R. Toltz Yesterday, I gave the results of the test of a 5000 h.p. triple expansion engine and a 250 h.p. compound engine working with superheated steam of different degrees of temperature, showing different percentages of economy in steam and coal according to the construction and design of the superheater.

2 I have known of the work that Mr. Foster has done. I have several of his tests, and I find that they check up within 1 or 2 per cent of the results I have given in the tables. I recollect one test especially, which was made at the Brooklyn water works with a Knowles compound duplex pump using a superheat of 225 degrees, and the saving of steam was 23 per cent, and the saving of coal 21 per cent. My table gives practically the same figures.

3 With a superheater of a good and sensible design, properly

applied and located in the boiler, a considerable economy in coal consumption will be shown. It is only a question of time when we shall have to come down to the same conditions that have existed in Europe for the last ten years; that is, we will have to design not alone turbines, but engines of all forms, so they will be able to take *highly* superheated steam.

No. 1155

USE OF SUPERHEATED STEAM IN AN INJECTOR

By STRICKLAND L. KNEASS, PHILADELPHIA, PA.
Member of the Society

In a large proportion of boiler plants it is customary to apply an injector to each boiler, either for continuous use, or to supplement or take the place of the feed pumps when temporarily out of service. Both the original cost and its up-keep are less than that of the pump, and the injector has the further advantage of always being ready for instant service.

2 The internal construction is simple, consisting essentially of a guiding nozzle for the jet of steam, a converging combining tube in which the steam impinges upon the entering water, and a diverging delivery tube to transform the energy of the combined jet into static pressure. The action of the injector is due to the transfer of the momentum of a jet of steam moving with a high velocity to a hollow cone of water, drawn into the tubes by the partial vacuum caused by condensation. The special construction of the tubes obtains intimate contact between the steam and water, and almost perfect condensation of the steam, with a reduction of the transverse area of the combined jet proportional to its increase in velocity; the resultant energy of the mass enables it to pass through the reduced area of the final tube of the apparatus and enter the boiler against initial pressure. Its action therefore depends not only upon the impact of the jet of steam, but upon its efficient and complete condensation, which occurs during its passage through the combining tube. At 180 pounds boiler pressure the jet must attain a terminal velocity of 163 feet per second to enable it to lift the check valve and enter the boiler. If the total length of the converging combining tube is 7½ inches, the interval of time during which the steam may be condensed is only 0.008 of a second and the acceleration is 20,000 feet.

3 It is therefore obvious that any condition which tends to

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diminish rapid condensation, operates against efficient mechanical action. An increase in the temperature of the water supply, moisture or superheat in the steam, all tend to reduce the proper ratio between the weight of the water delivered into the boiler to that of the motive steam.

4 It is therefore essential that the condition of the steam permit instant and complete condensation and also that its velocity reach a maximum at the instant of impact with the water. Many experiments have been made by the writer[1] to determine the most efficient shape of diverging steam nozzle and also the terminal velocity of the discharging jet. Results of experiments with saturated steam prove that the flow is in accord with the well known formula based upon adiabatic expansion. The velocity of superheated steam is slightly higher as it follows the law of a perfect gas until condensation due to expansion begins; the velocity of the combined jet would consequently be increased, but this advantage is overbalanced by the shorter interval of contact and condensation, during which the additional heat in the steam must be abstracted and the mechanical efficiency is lowered; if there is no loss from radiation, the thermo-efficiency will still be 100 per cent. To obtain good results from an injector with superheated steam, it would be necessary to modify the design and proportion of the tubes and nozzles.

5 The practical effect of superheated steam upon the action of an injector is to reduce the maximum capacity, increase the minimum capacity, and to lower the limiting temperature of the water supply with which the injector can operate. Further, with high pressure and superheat, an inefficiently designed instrument is inoperative. It is therefore advantageous and usually practicable to have a special pipe to supply the injector with saturated steam.

Proceedings, Vol. 12, p. 897. Proceedings Engrs. Club Phila. Oct. 1891.

No. 1156

SUPERHEATED STEAM ON LOCOMOTIVES

The Use of Superheated Steam on Locomotives in the United States and Canada

By H. H. VAUGHAN, MONTREAL, CANADA
Member of the Society

APPLICATIONS

Apart from an experimental application of a smoke-box superheater on the Chicago, Burlington & Quincy Railway, between 1870 and 1874, the first application of superheated steam in North America was made by Mr. Roger Atkinson, then mechanical superintendent of the Canadian Pacific Railway, who applied a "Schmidt" smoke-box superheater to a 4-6-0 simple freight engine in 1901. In 1903 Mr. E. A. Williams, then mechanical superintendent of the same road, applied a "Schmidt" smoke-tube superheater to two 4-6-0 compound freight engines, and the results obtained from these installations were exceedingly satisfactory, the first engine showing a saving of 25 per cent over corresponding simple engines and 18 per cent over corresponding compound engines of the same class, while the latter engines showed a saving of from 15 per cent to 20 per cent over similar compound engines using saturated steam.

2 In 1904 the New York Central & Hudson River Railway applied a "Cole-Field" smoke tube superheater to a 4-4-2 passenger engine, and in the latter part of the same year the Canadian Pacific Railway purchased 41 engines, 21 of which were equipped with this type of superheater, and 20 with the "Schmidt" smoke-tube superheater. Since that date all engines, other than those in switching service, constructed on the Canadian Pacific Railway have been equipped with smoke-tube superheaters of various types, and on December 31, 1906, there were in service on this road 197 engines equipped with superheaters of the following types.[1]

[1]For full details see Proceedings Railway Master Mechanics Association, 1905.

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TYPE	NUMBER
Schmidt smoke-box	1
Schmidt smoke-tube	32
Cole Field-tube	21
Cole return bend	55
Vaughan-Horsey return bend	88

3 At the present time this road has on order 175 locomotives for delivery during the present year, all of which are to be equipped with the "Vaughan-Horsey" type of superheater, which will make a total of 372 engines to which this principle has been applied.

4 On the railways in the United States the progress has been far less rapid, and a reasonably complete list of the engines equipped at the end of 1906 is as follows:

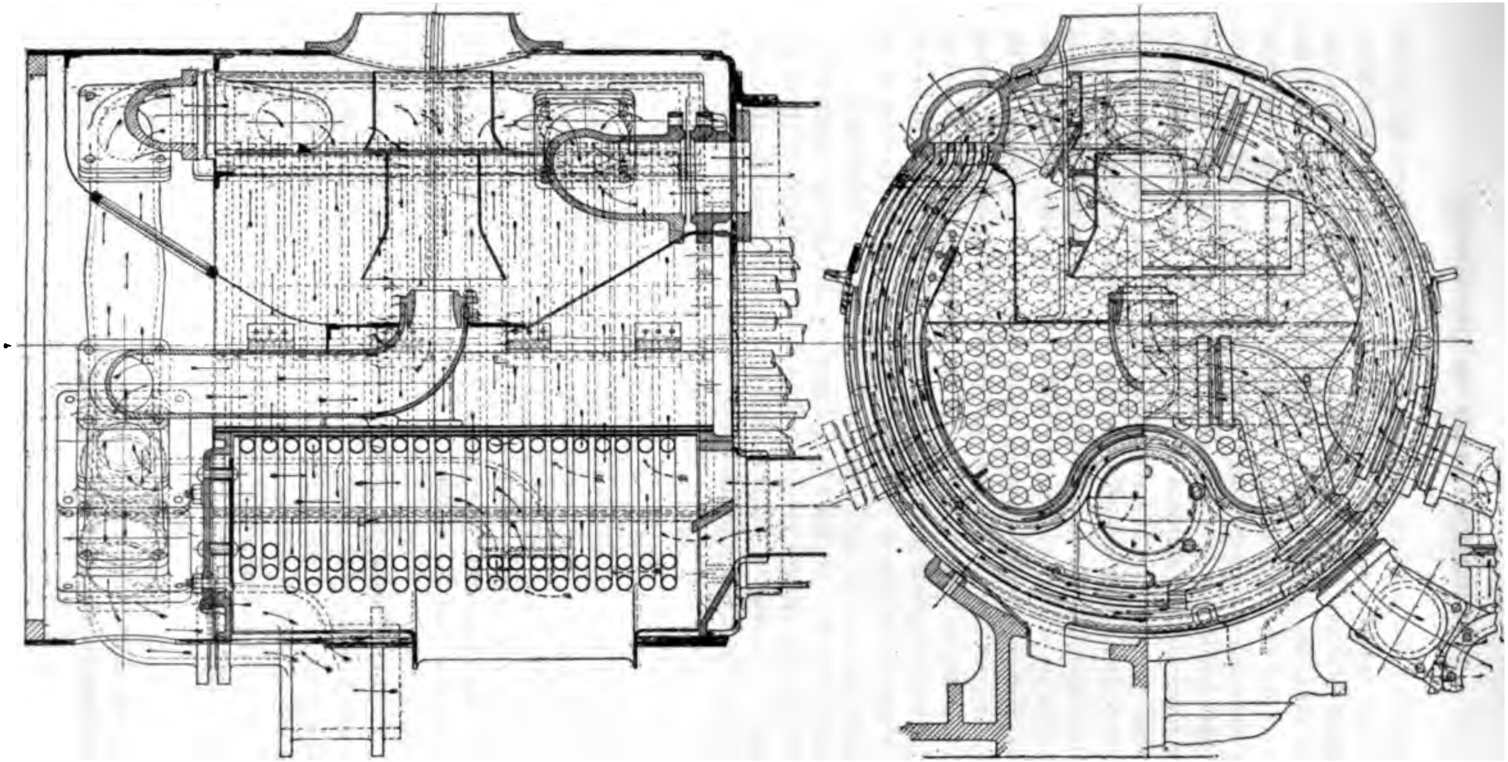
Railway	Cole	Schmidt	Vaughan-Horsey	Total
N. Y. C. & H. R.	1			1
C. B. & Q. Ry.	1	2		3
Rock Island	6			6
M. St. P. & S. S. M.	1			1
C. & N. W. Ry.	1			1
Boston & Maine	1			1
L. S. & M. S.	1		1	2
Totals	12	2	1	15

TYPES

5 With the exception of one engine, viz., the first to which a superheater was applied on the Canadian Pacific Railway, all the engines enumerated above have been equipped with superheaters of the type known as the smoke-tube, this particular engine being equipped with a superheater of the smoke-box type, shown in plan and elevation Fig. 1.

6 In this design the superheating pipes are placed in the smoke-box of the locomotives, but as the temperature of the gases in the smoke-box after passing through the evaporating tubes is insufficient to superheat the steam to the requisite degree without an impracticably large amount of heating surface, a tube of large diameter leads from the firebox to the front tube sheet, by which a considerable portion of the flue gases are delivered into an annular chamber in the front end at a high temperature. The superheater tubes are located in this chamber and are thus exposed to gases of a relatively high temperature, so that the superheating surface is exceedingly efficient.

7 The steam from the boiler passes from the dome through the



Course of Steam Shown by ——→

Course of Gases Shown by – – –→

FIG. 1 SMOKE BOX SUPERHEATER, SCHMIDT'S PATENT dry pipe, into the rear end of a header placed on the right side of the smoke-box near the top, which is separated into two compartments by a transverse partition about midway of its length. From the rear compartment the steam passes through the superheater pipes to the back end of a similarly located header on the opposite side which is of the same length as the first header, but not divided into compartments. From this header the steam passes through a second set of superheater pipes to the front end of the first header, and thence through the steam pipes to the steam chest. The annular space previously referred to is partitioned off from the remainder of the smoke-box and an opening is provided through which the gases, after passing around the superheater pipes, are drawn into the body of the smoke-box and thence through the stack by the action of the exhaust. This opening is provided with a damper which automatically opens when steam is admitted to the superheater and closes when it is shut off, so that the superheating pipes are only exposed to the flow of heated gases when the steam is flowing through, as the temperature of the gases passing through the large flue is sufficient to injuriously overheat them if no flow of steam is taking place through the superheater.

8 While the results obtained have been satisfactory, there are necessarily a number of joints in the front end and considerable complication of detail which in the opinion of the writer will make it very doubtful whether this type of superheater will be extensively applied in American practice.

9 The smoke-tube type of superheater which has been the one generally applied, varies almost entirely in the arrangement of the headers in the front end. The various types of Schmidt, Fig. 2 and Fig. 3; the Cole Field-tube, Fig. 4; the Cole return-bend, Fig. 5; and Vaughan-Horsey, Fig. 6, while varying slightly in the arrangement of the superheater pipes in the smoke tube, differ largely in the form of the headers and the method by which the superheater pipes are attached to them.

10 The Cole Field-tube design is not of much practical interest as it has been but little used, and on the Canadian Pacific Railway it has been taken out of engines which were equipped with it as it was found impossible to prevent the smoke-tubes from stopping up. The same results have been obtained on other roads from which it would appear that the return-bend type is the only one giving satisfactory practical results.

11 The return bend type may be so arranged that the ends of each pair of superheater pipes enter the saturated and superheated steam headers respectively, as is shown in Fig. 3, or the ends of each alter-

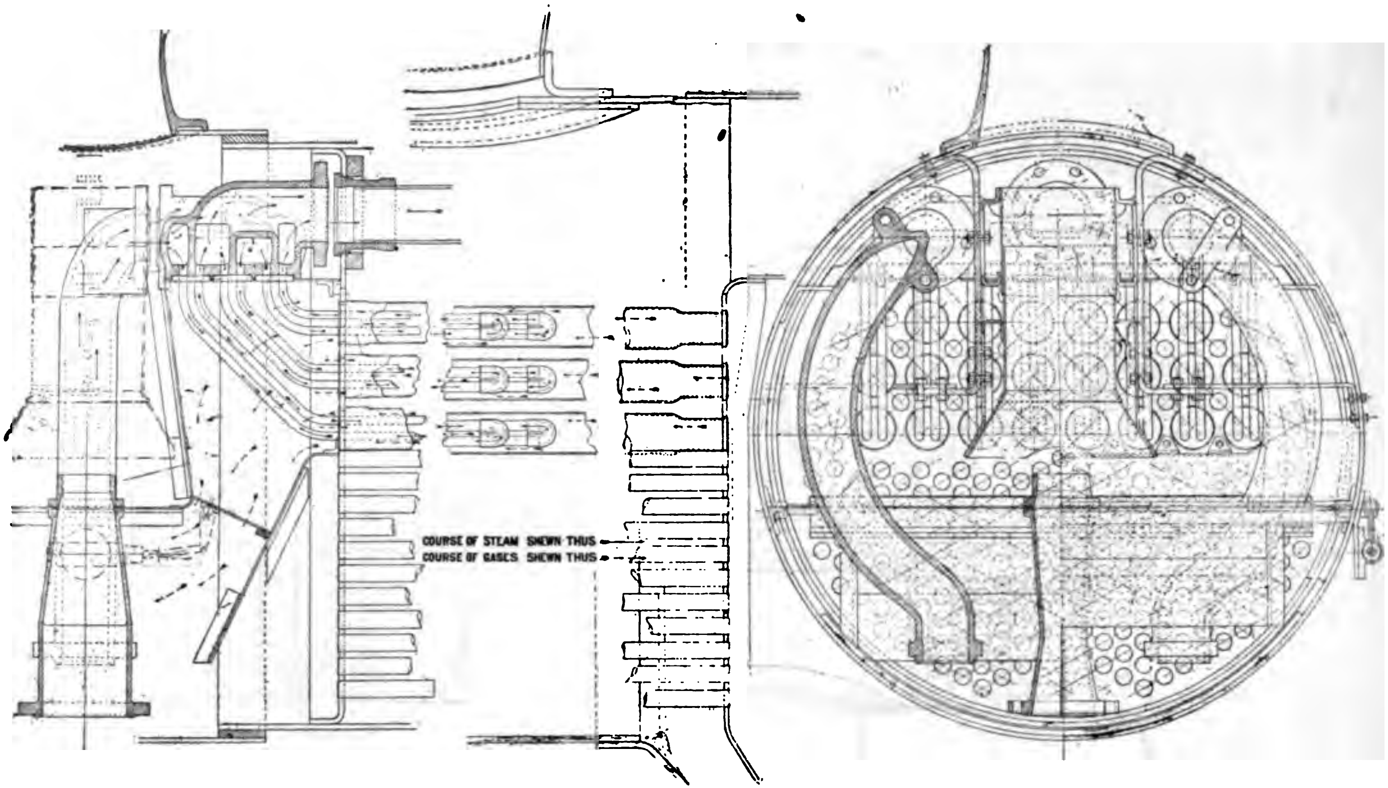
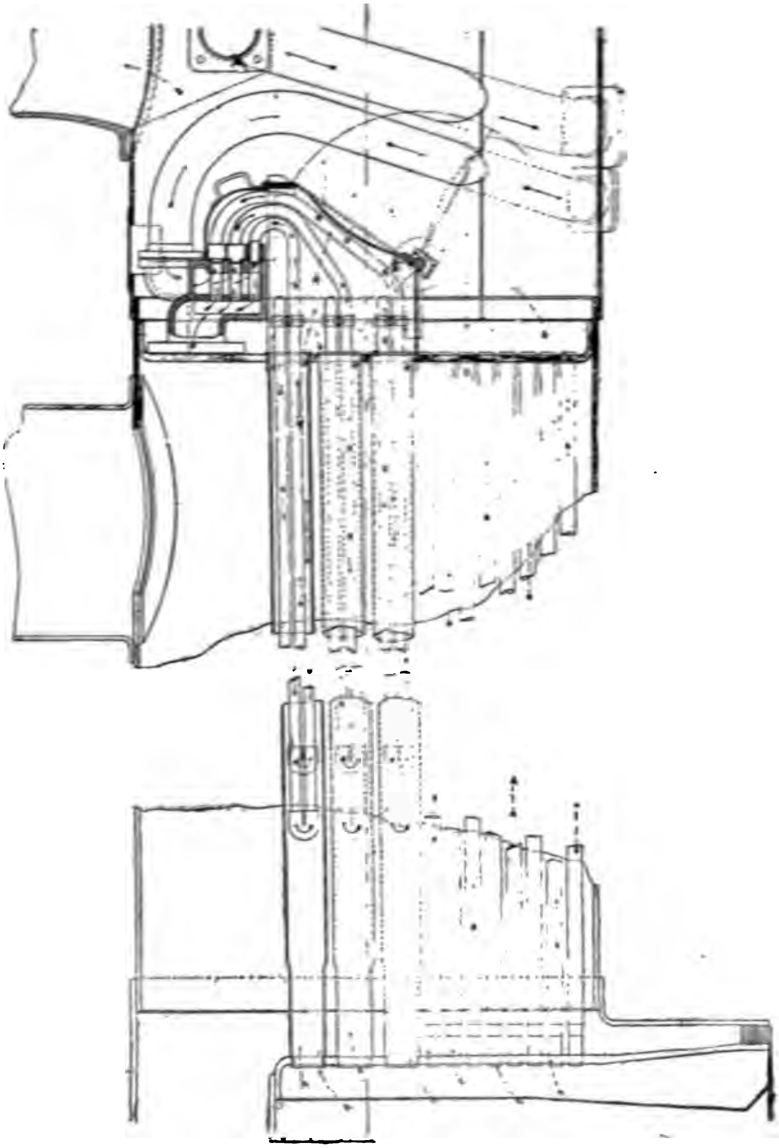


FIG. 2 SMOKE TUBE SUPERHEATER, SCHMIDT'S PATENT



Course of Steam shown by
Course of Gases shown by

FIG. 3 FIRE TUBE SUPERHEATER, SCHMIDT'S PATENT. SECTION nate pair may be joined together, thus forming a double loop in each smoke tube. It will therefore be seen that the actual variation of the

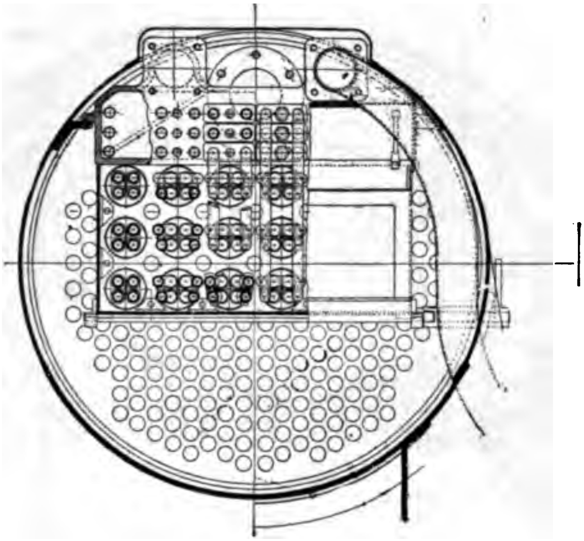


FIG. 3. FIRE TUBE SUPERHEATER, SCHMIDT'S PATENT
END VIEW

Cole and Vaughan-Horsey design from the Schmidt consists in the arrangements of the headers. In the Schmidt design each group of superheater pipes is united into one flange, which is detachable from

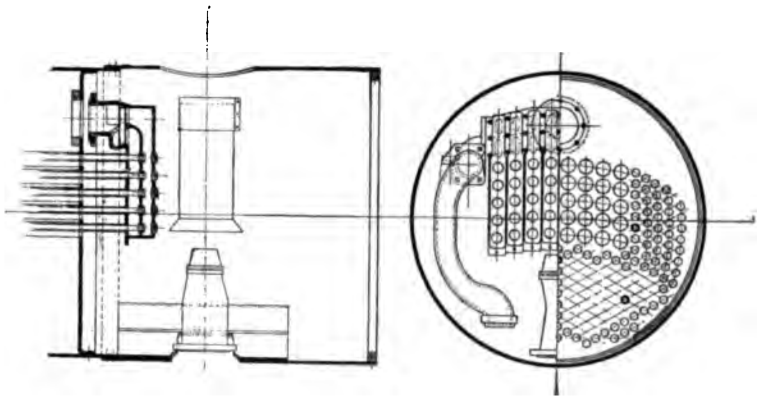


FIG. 4 THE COLE FIELD-TUBE

the header. In the Cole design each vertical row of superheater pipes is connected into a sub-header, the sub-headers being detachable from the main header. In the Vaughan-Horsey type each pair of super-

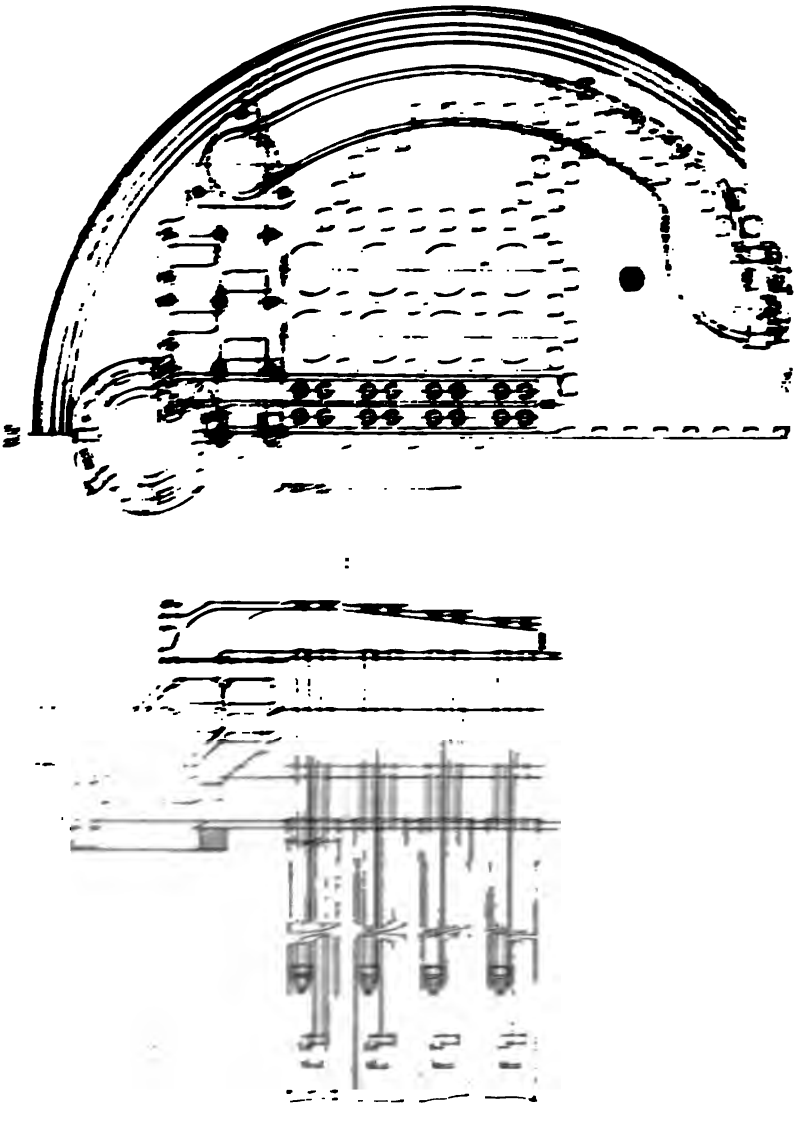


FIG. THE COLE BOTTOM BEND TYPE

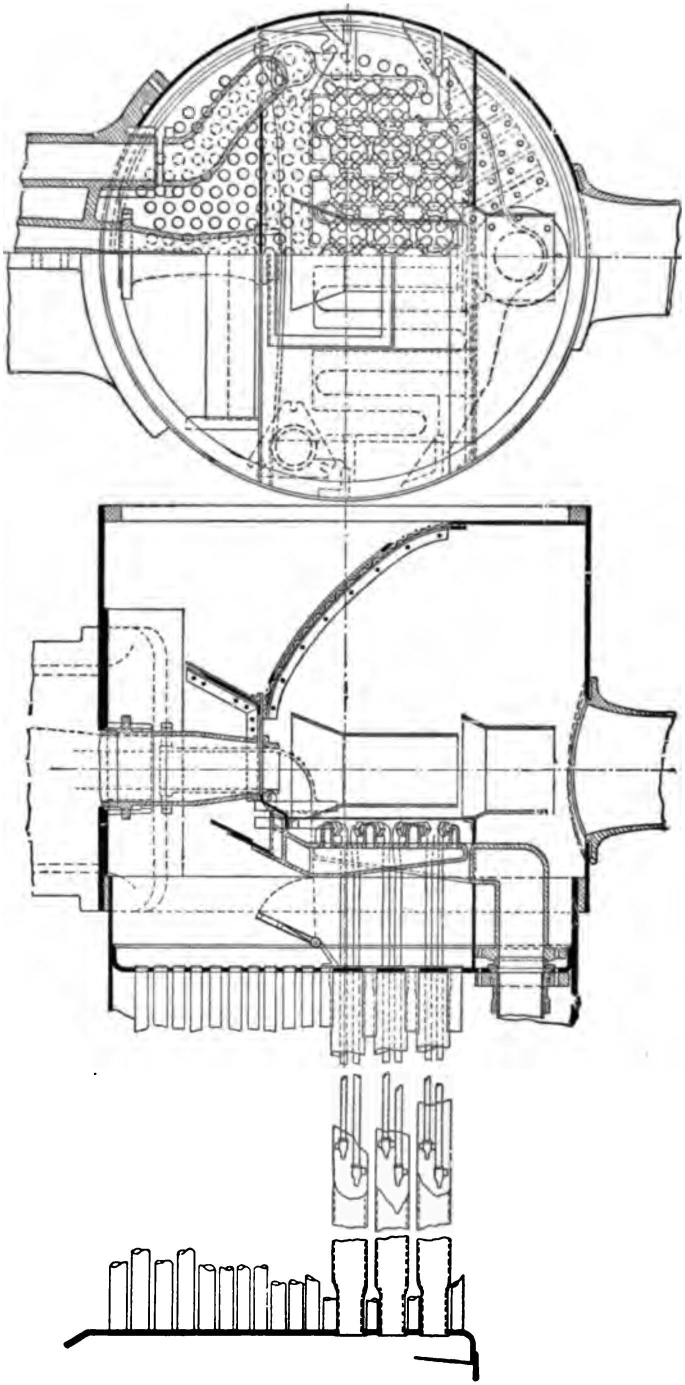


FIG. 6 THE VAUGHAN-HORSEY TYPE

header pipes is detachable from fittings screwed into the main headers which in this case are entirely separate and placed one above the other.

12 In all these arrangements the steam from the boiler is led by a dry pipe into the saturated steam header, thence through the loops of superheater pipes located in the smoke tubes to the superheated steam headers from which it is led by the steam pipes to the cylinders. The superheater headers are partitioned off from the body of the smoke-box, the partition extending to the flue sheet and provided with an opening controlled by an automatic damper, as in the previously described smoke-box superheater, by which the flow of gases from the fire-box through the smoke tubes is permitted while steam is flowing through the superheater pipes, but prevented when the throttle is shut, and the flow of steam stopped. A detailed description of these various types is given in the Proceedings of the Master Mechanics Association, 1905, and New York Railway Club, April 20, 1906.

13 There is one point, however, that the writer wishes to emphasize, which is that while these different arrangements of smoke tube superheaters are given different names, the Cole and Vaughan-Horsey types are simply modifications of the Schmidt design introduced into America in 1903, and while the elements of this design were perhaps not entirely original with Mr. Schmidt, as early French patents existed showing substantially a similar construction, at the same time the credit of this modern construction is entirely his, and the other two types simply vary from it in their mechanical construction.

CONSTRUCTION

14 The large smoke tubes now made with a 5 inch outside diameter reduced to 4 inch outside diameter for a short distance from the firebox end have usually been of solid drawn steel tubing, although the Canadian Pacific Railway is now experimenting with some lap-welded charcoal iron. These tubes are threaded at the back end and screwed into the firebox tube sheet. The thread in the tube sheet is cut in position by a tap having a guide spindle fitting in a bushing in the front tube sheet in order to make this thread correspond accurately to the axis of the tube. After being screwed in, a taper mandril is driven tightly into the tube and the latter is then staved up with a calking tool, so as to expand it as solidly as possible into the thread in the tube sheet. It is then rolled and beaded in the usual way at both ends.

15 This method of setting has proved exceedingly satisfactory. Cast iron and mild steel ferrules are used at the firebox end occasionally. They appear to offer some advantage in bad water districts, but are not necessary where the water is good. The superheater pipes are made of solid drawn steel tubing $1\frac{1}{4}$ inch outside diameter with walls $\frac{5}{32}$ inch thick. The return bends have so far been made of cast steel, but experience shows that it will be preferable to construct them of drop forgings in the future and they should be of sufficient length to cover the threads on the ends of the superheater pipes over which they are screwed. The connection of the superheater tubes to the headers varies materially in the three designs. In the Schmidt the pipes are expanded into flanges, the pipes in each smoke tube leading to one flange, and in the regular Schmidt arrangement these flanges are attached to the header by two clips between each pair of flanges, each clip being secured by a stud screwed into the header, and copper gaskets are used to make the joints between the flanges and the header.

16 In the Cole design the pipes are expanded into the sub-headers and the joints between the sub-headers and main headers are made by round wire copper gaskets, each pair of headers being secured to the main header by a clip bearing on the headers and secured to the main header by a stud.

17 In the Vaughan-Horsey design, the end of each superheater pipe is up-set, forming a flanged connection and bent at right angles to form a joint with the fittings attached to the different headers. A forged steel union nut engages the flange on the superheater pipe, and screws on to the threaded portion of the fittings, the joints being made by a small copper gasket. In the Schmidt and Cole designs the headers have usually been made of cast steel, but in the Vaughan-Horsey type a high grade dry sand casting has been found satisfactory.

ECONOMICAL RESULTS

18 The results obtained in coal economy have, on the whole, been exceedingly satisfactory. The results obtained from the first three engines on the Canadian Pacific Railway have already been referred to. Subsequent results on a large number of superheaters have not however shown as large a percentage of saving as would naturally be expected, when a device of this nature is applied in sufficient quantities to insure the engines with which it is equipped being treated in exactly the same way as other engines to which no particular attention is given and taking their chance with reference to the ability of the engine crews which handle them.

19 Unfortunately it is difficult to compare superheater simples with ordinary simples on the Canadian Pacific Railway, as previous to the introduction of the superheater most of the recent power purchased was of the compound type, and care has also to be exercised in making comparisons on account of the large variation in the coal consumed per ton mile on the Canadian Pacific in the summer and winter.

20 The most satisfactory comparison is arrived at by taking engines working over similar sections during the summer months, and the following table shows the performance of 2-8-0 superheater simples as compared with similar 2-8-0 compound and a 4-6-0 compound of about equal weight and also similar in design. The superheaters are of two types, M-4a being a Schmidt smoke tube return bend and M-4b a Cole Field-tube. M-3 are 2-8-0 compounds and D-9 a 4-6-0 compound. These results are those obtained during the summer of 1905.

TABLE 1

Section	Class of Engine	Total coal consumed	Coal consumed per unit mile	Relative consumption
Chalk River-North Bay.....	M—4b Cole	2045¾	126	97
	M—4a Schmidt	954½	112	85
	D—9 Comp'd	175	114	86
	M—3 Comp'd	1121¾	132	100
North Bay, Cartier, Webbewood.....	M—4b Cole	1473¾	127	100
	M—4a Schmidt	568¼	106	87
	D—9 Comp'd	510¾	113	92
	M—3 Comp'd	1756	122	104
Schreiber-Fort William.....	M—4b Cole	134½	145	122
	M—4a Schmidt	34¾	96	81
	D—9 Comp'd	743¾	141	118
	M—3 Comp'd	3576	119	100
White River, Schreiber.....	M—4b Cole	2744¾	159	119
	M—4a Schmidt	89	134	101
	D—9 Comp'd	775½	150	113
	M—3 Comp'd	4758½	133	100
Chapleau-White River	M—4b Cole	265	140	96
	M—4a Schmidt	4126¾	121	83
	D—9 Comp'd	545½	142	97
	M—3 Comp'd	515	146	100
Chartier-Chapleau..........	M—4b Cole	245½	126	82
	M—4a Schmidt	3684¾	117	76
	D—9 Comp'd	565¾	148	96
	M—3 Comp'd	728½	154	100

21 The D-9 engines may also be advantageously compared against three classes of 4-6-0 simple superheater engines of the D-10a class equipped with Schmidt smoke-tube return bend, the D-10b with a Cole return bend and the D-10c with a Vaughan-Horsey return bend.

22 These engines were run against each other during the months of September, October, November, December and January, inclusive, on the Canadian Pacific between Fort William and Winnipeg, and the general result is given in Table 2, with reference to which it should be noted that this section of the line is an exceedingly favorable one for compound locomotives.

23 Previous to the introduction of the superheater, the D-9 engines had been by far the most economical yet used on that section. The superior economy of the D-10c engines is not easy to explain, and although the writer has discussed this question at some length before the New York Railway Club, he does not feel that there is sufficient data on the subject to regard it as a definite fact.

TABLE 2

Section	1300, D—9 Comp.		700, D—10a Schmidt-Sup.		710, D—10b Cole Sup.		740, D—10c V. H. Sup.	
	Coal used	Relative consumption	Coal used	Relative consumption	Coal used	Relative consumption	Coal used	Relative consumption
Fort William to Ignace	13,144	100	207	101.0	2,993	88.5	5842	84.7
Ignace to Kenora	2,520	100	6073	98.3	14,082	105.0		
Kenora to Winnipeg	8,416	100	2170	100.8	10,443	100.5		
Total	24,080	100	8,450	100.7	28,418	99.5	5,842	85.5

24 In the early part of 1906, the Cole superheaters were removed from the M-4 engines, and therefore during 1906 were used as simple engines, thus offering a good basis for comparison with the M-4a engines. This year some other classes of engines have been introduced. Two 4-6-0 simple passenger engines Class E-5 have been converted to Vaughan-Horsey superheaters, class E-5d and some 2-8-0 simple engines class M-4e have been equipped with the same device, as well as some Pacific type 4-6-2, passenger engines class G-1-2. For purposes of comparison the results obtained from 2-8-0 class compound engines, M-1-2 of slightly smaller size than the M-4 are also shown. These engines are an economical and satisfactory type and offer a good basis for comparison.

25 Selecting sections on the Canadian Pacific on which sufficient work was done, the simple, compound, and superheater engines of reasonably similar types, the following table is presented.

TABLE 3 FREIGHT SERVICE

Section	Class of engine	Coal consumed	Coal consumed per unit mile	Relative consumption
Newport—Outremont	D-10b Cole	207¾	128	75
	D-10c V-H	370	163	96
	M-3 Comp.	381	148	87
	M-4b Simple	5877	170	100
	M-4e V-H	220½	108	64
Megantic—Farnham	D-10b Cole	342¾	182	86
	D-10c V-H	2439	176	83
	M-3 Comp'd	124¾	208	98
	M-4b Simple.	3025	213	100
Smith's Falls—Havelock	D-9 Comp'd	3579	135	109
	D-10b Cole	7410	124	100
	D-10c V-H	3209	125	101
	M-1-2 Comp'd	373½	136	110
Havelock—Toronto	D-9 Comp'd	494	147	100
	D-10b Cole	521	147	100
	D-10c V-H	501	136	93
	M-1-2 Comp'd	4716	147	100
Chalk River—North Bay	D-10c V-H	2909	133	100
	M-4a Schmidt	321½	102	77
	M-4b Simple	305	133	100
North Bay—Cartier	D-10b Cole	311	138	98
	D-10c V-H	2257	118	84
	M-3 Comp'd	4425	141	101
	M-4a Schmidt	501	131	94
	M-4b Simple	505	140	100
Cartier—Chapleau	D-10b Cole	219½	121	94
	D-10c V-H	2837	122	95
	M-3 Comp'd	1264	153	
	M-4a Schmidt	2287	126	98
	M-4b Simple	502	128	100
Chapleau—White River	D-10b Cole	716	133	92
	D-10c V-H	2763	125	87
	M-3 Comp'd	1406	155	107
	M-4a Schmidt	2642	130	90
	M-4b Simple	403	144	100
White River—Schreiber	D-10b Cole	2977	192	130
	D-10c V-H	231	134	91
	M-3 Comp'd	2188	158	107
	M-4a Schmidt	1536	131	89
	M-4b Simple	1312	147	100
	M-4e V-H	234½	125	85

TABLE 3—Continued

Section	Class of engine	Coal consumed	Coal consumed per unit mile	Relative consumption
Schreiber—Fort William	D-10b Cole	2,719	120	91
	D-10c V-H	239½	118	89
	M-3 Comp'd	2051	137	104
	M-4a Schmidt	1176	116	88
	M-4b Simple	777½	132	100
	M-4e V-H	252¾	178	135
Fort William—Ignace	D-9 Comp'd	967¾	97	98
	D-10b Cole	2381	99	100
	D-10c V-H	15304	88	89
Ignace—Kenora	D-9 Comp'd	472½	95	100
	D-10a Schmidt	741	96	101
	D-10b Cole	15767	95	100
	D-10c V-H	113½	99	104
	M-4e V-H	3173	89	90
Kenora—Winnipeg	D-9 Comp'd	2380	114	114
	D-10a Schmidt	904¾	88	88
	D-10b Cole	16514	100	100
	D-10c V-H	215	91	91
Swift Current—Med. Hat	D-9 Comp'd	17322	165	100
	D-10a Schmidt	830¼	141	81
	D-10b Cole	778¼	168	102
	M-1-2 Comp'd	1567	194	117
Med. Hat—Calgary	D-9 Comp'd	1443	146	100
	D-10a Schmidt	616	122	84
	M-1-2 Comp'd	6058	155	107
Field—Revelstoke	M-4b Simple	1158	317	100
	M-4e V-H	3664	281	89

PASSENGER SERVICE

Section	Class of engine	Coal consumed	Coal consumed per unit mile	Relative consumption
Havelock—Toronto	E-4-5 Simp.	379	360	100
	G-1-2 Sup. V-H	1735	220	61
Swift Current—Med. Hat	D-9 Comp.	1381	341	100
	D-10a Schmidt	5073	195	57
	D-10b Cole	163	228	67
Chalk River—North Bay	E-4-5 Simp.	3651	215	100
	E-5d,e V-H	133½	159	74
	G-1-2 V-H	716	203	95
North Bay—Cartier	E-4-5 Simp.	2091	197	100
	E-5d,e V-H	318	195	99
	G-1-2 V-H	2968	166	84
Cartier—Chapleau	E-4-5 Simp.	2896	186	100
	E-5d,e V-H	484¼	158	85

26 In the majority of cases the superheater engines showed a decided saving, and the results between the 4-6-0 and 2-8-0 vary somewhat in accordance with the relative economy of these two general types of engines. Under some conditions the 2-8-0 are more economical, while under other conditions there is very little difference.

27 A very interesting result is that obtained from Field to Revelstoke. These are engines working on very heavy grades and are fairly comparable for two classes of locomotives involved, as they were both working together, and it will be noticed that a saving of 11 per cent for the six months in favor of the superheaters was obtained. For the larger portion of this section the engines were working at long cut-offs where the gain from superheat would be expected to be less marked.

28 An interesting difference is shown between Swift Current and Medicine Hat. In freight service the D-9 freight compound engines show up exceedingly well in comparison with superheaters, but in passenger service on the same section the superheaters are much more efficient, the compound taking about 60 per cent more coal, due to the loss in efficiency in the compound in passenger service and the relative gain in the superheater.

29 Tests on other roads so far as information has been received show in general a reasonable amount of saving. On the Chicago, Burlington & Quincy the road records show but little difference, and on this road the experience was not satisfactory, due very probably to trouble experienced with leakage at the joints in the headers.

30 On the Boston & Maine comparative tests of two 4-6-0 engines equipped with Cole return bend superheaters in passenger service showed a gain of 14.7 per cent in ton miles per pound of coal on the engine equipped with superheated steam.

31 On the Chicago & North Western Railway tests comparing identical 4-4-2 passenger engines with and without Cole superheaters showed an economy of 9 per cent in coal in favor of the superheater.

32 On the Lake Shore & Michigan Southern tests of engines equipped with Cole and Vaughan-Horsey superheaters compared to similar engines using saturated steam showed a saving of 18.8 per cent for the Cole and 22.1 per cent for the Vaughan-Horsey superheater in coal per ton mile.

33 From the general results of these figures it would appear safe to state that from 10 to 15 per cent saving is obtained in freight service and 15 to 20 per cent in passenger service on engines equipped with superheaters as compared with those using saturated steam

although this economy will be to a considerable extent lost if leakage occurs at the headers.

MAINTENANCE RESULTS

34 Results obtained from superheaters on the Canadian Pacific Railway are such as to justify a continued construction of engines equipped with this device. The past three years have developed many troubles, but they have also indicated their remedy.

35 The automatic damper, first looked on as a desirable attachment, has proved to be a most important factor in the successful operation of the superheater engine. During the first year's experience it appeared to make but little difference whether this damper was operative or not, but it has been found that if neglected there is a gradual but serious deterioration in the ends of the superheater pipes. The structure of the metal becomes entirely destroyed and leaks occur at the return bends, and the metal in the pipes changes its structure until it can be broken in the hands. The damper is not difficult to maintain, simply requiring proper attention, but the design which has been used and which was introduced with the original Schmidt superheater is not satisfactory, and can certainly be very much improved, and its maintenance made easier.

36 The writer sees no reason whatever for abandoning a valuable and important principle such as the use of superheated steam because troubles have been incurred through neglect in maintaining a small attachment which could easily have been attended to had its importance been appreciated, and after three years' experience feels justified in stating that if the dampers are properly maintained the trouble through the destruction of the ends of the superheater pipes will not occur.

37 With properly maintained dampers the next source of trouble is leakage at the connections of the superheater pipes to the headers. In the Schmidt design properly put up, this occurs but very seldom, and the majority of engines with this arrangement will run from shopping to shopping without attention. The objection that has developed in the Schmidt arrangement is that should any leakage occur, especially in the flanges attached to the upper rows of superheater pipes, it is practically necessary to take down all the flanges and make the joints afresh, and this takes considerable time with a corresponding loss in the service of the engine.

38 The greatest trouble has come from having to do this on account of the leaks occurring at the return bends caused by dampers not being properly maintained, but apart from this trouble the

writer considers the Schmidt to be a satisfactory design, although the inability to take out any defective element without disturbing others is to his mind a great objection.

39 The Cole type of superheater has given considerable trouble from leakage at the joints between the sub-headers and the main header. While this may be overcome by a modification in the design, the number of defects which have developed has been most serious. The joints are probably loosened by the action of the weight of the superheater pipes working backward and forward when the engine is in service, and the loosening of the joints causes a leakage of steam across the face of the copper gasket and rapidly cuts it away. Arrangements are now being made to support the lower ends of headers so as to prevent their movement, and it is thought that this will largely overcome the difficulty No trouble is experienced in the joints between the superheater pipes and sub-headers, but the latter are difficult to take out one at a time without disturbing those adjacent, and thus in case of a defective superheater pipe it is generally necessary to make all the joints over again, which means considerable work.

40 The Vaughan-Horsey type gave considerable trouble at first on account of the fittings and union nuts being made of brass, which deteriorated in the heat of the gases, but since these parts have been made of steel, the trouble has been practically overcome, and on account of this design permitting any pair of superheater pipes to be withdrawn without disturbing another, a defective element can be taken out, the joints blinded, and the element replaced at the first convenient opportunity, which is of considerable advantage in roundhouse maintenance where engines are worked as hard and as continuously as they are in American practice.

41 In general the maintenance of superheaters has not proved expensive, but the troubles enumerated have led to annoying and inconvenient delays to power, which if not treated on their merits might be held to condemn the device, but when analysed, there seems to be no insuperable difficulty in remedying these, and with the proper remedy the writer firmly believes there is nothing about a superheater which should lead to its giving a less efficient service than a simple engine, and the slight additional expense is amply warranted by the saving obtained.

42 The smoke tubes have given but little trouble, in fact less trouble than the ordinary 2 inch or 2¼ inch tubes which they replaced. On some bad water districts where the small tubes have to be reset every 20,000 or 30,000 miles, the smoke tubes can be allowed to run

through at least one resetting of the small tubes, which is probably due to the considerably better circulation and their greater thickness. Some difficulty has been experienced from the smoke-tubes stopping up with cinders especially with the Field-tube type of superheater which seems particularly bad in this respect. With the return bend type however on the majority of the roads there is no serious difficulty in this respect, although it is necessary to see that the tubes are properly and systematically blown out and kept clean. The expense in the labor involved in doing this is, however, negligible.

43 The maintenance of valve and piston rod packing is slightly greater on engines running with superheated steam than on simple engines, but with proper lubrication the difference is not serious. It is necessary to use hard close grained cast iron for the valve and piston rings, but with suitable types of piston and valve stem packing there is practically no difference in the maintenance of simple and superheater engines.

44 In general, the writer believes that, while it may be necessary to insist on the proper maintenance of superheaters, the expense involved is not great, and with the proper maintenance and the improvement in detailed design which experience is leading to, there will be practically no decrease in the mileage to be obtained from the superheater as compared to the simple engine, and that the additional cost of maintenance will be unimportant.

LUBRICATION

45 When engines equipped with superheated steam were introduced, it was considered necessary to use forced lubrication to the valves and cylinders and this belief led to considerable trouble owing largely to the various forced feed lubricators employed which did not work satisfactorily with their rapid wear and the small amount of attention they received from the enginemen. During the past year, however, it has been found that the ordinary hydrostatic sight feed lubricator is quite as satisfactory on engines using superheated steam as on those using saturated, but it is necessary with the oil at present employed to lubricate the cylinders in addition to simply lubricating the valves, as in common simple engines. The present practice is to use separate feeds to each end of valve and to center of cylinder near the top and with this arrangement no difficulty is experienced with lubrication, although the writer believes it would be advantageous to use a rather heavier valve oil than is at present customary.

CONCLUSIONS

46 The writer's experience with locomotives using superheated steam has not been free from vexations and annoying troubles, but it has on the whole been exceedingly satisfactory.

47 The troubles encountered are being overcome as experience develops their cause and the saving obtained is apparent in the reduction of the amount of coal used per ton mile on various divisions of the road as superheater locomotives are introduced. The additional capacity of the engines and the reduction of the work required of the fireman, enabling trains to be handled better, and the development of an engine which in extremely cold weather can be as easily maintained as a simple engine with an economy equal or superior to that of a compound is an important advantage to any railroad working in northern latitudes.

48 So far as can be seen at present there is no valid reason for discontinuing the application of superheaters, and the writer expects that a considerable increase in the number in use will take place in the next few years.

DISCUSSION

Mr. M. E. R. Toltz: Mr. Vaughan states that only 13 locomotives are at this time equipped with superheaters in the United States. He did not take into consideration the two locomotives on the Great Northern Railway and three on the Northern Pacific to which are applied the Schmidt flue superheater.

2 On the Great Northern Railway one of the locomotives is of the Pacific type, which pulls the fast passenger train over the Rocky Mountains on the Kilispell division; the other is of the prairie type and is running in freight service on the St. Paul and Willmar division, having a maximum grade of 0.4 per cent. I cannot at the present time give any information about the Northern Pacific engine.

3 A year ago, Mr. Vaughan read a paper before the New York Railway Club on superheated steam as applied to locomotives. At that time he gave comparative results obtained on the Canadian Pacific Railway with different types of superheaters, which also showed the economy in coal consumption. I doubted very much that the comparative statements of the different engines were reliable, because, as Mr. Vaughan admitted, the coal was not weighed as it should have been, but the records of the coal heaver were taken as correct.

4 On the Great Northern, service tests only have been made and

we have tried to get as close and correct a coal record as we possibly could and it was found that the passenger engine with superheated steam over a sister engine with saturated steam gave a coal saving of from 15 to 18 per cent and a steam saving of from 23 to 27 per cent. With the prairie type superheated steam engine in freight service an average of from 12 to 15 per cent saving in coal and about 18 per cent saving in steam was obtained. These results were taken from the monthly performance sheets.

5 In the beginning of this year the grade of coal was changed on the St. Paul and Willmar division and soon it was reported that the freight engine with the superheater was falling back and that there was not the economy shown before. Upon investigation it was found that about one hundred and sixty of the lower flues in the boiler were clogged up almost solidly by oxid of iron which was carried along through the flues from the coal because the latter contained (if I remember rightly) between 3 and 3½ per cent of iron pyrites. Upon consultation with the mechanical department, it was found necessary to make changes in the front end to increase the draft in the lower flues after the clogged up flues had been drilled out, which took about ten days.

6 The dampers which enclosed the superheater elements in the front end were taken out and instead a so called common front end consisting of a deflecting plate with netting was put in place. Next, the draft was decreased from 3½ to 2 inches and this was sufficient to keep the lower flues clean, which fact has been established ever since the change was made, because they have not shown any deposit of this oxid of iron with the same quality of coal. This is now two months ago, but by this change, the draft in the upper flues was decreased so much that instead of getting a superheat of from 200 to 225 degrees, only a superheat of 90 degrees was obtained (the temperature of this superheat was taken at the steam chest) and in consequence, saving in coal was reduced to 8 or 8½ per cent.

7 Further tests will be made by opening up the deflective plate on top, so that more gases heated to a higher degree will pass through the large smoke tubes in which the superheater elements are located, whereby superheat will be increased.

8 I do not agree with Mr. Vaughan that the dampers are absolutely necessary in the front end to protect the superheater elements, but to be on the safe side, the throttle valve which at present remains in the dome on top of the steam pipe will be changed and located between the superheated steam chamber and the steam chests, so that at all times the superheater elements will be filled with steam

which is not the case in the present design of superheaters when the throttle valve is closed. A further improvement that I am going to try, I do not know whether it will be successful, is to make a connection between the superheated steam chamber and the dome by a pipe, so that when the engine is not working or the throttle valve is closed, a circulation through the superheater elements will be created. My theory is that superheated steam, being lighter, will flow into the dome, and saturated steam will therefore be drawn through the dry pipe into the superheater elements.

9 But, at any rate, Mr. Vaughan is correct in saying that superheated steam is going to stay and will be used in the future on locomotives. The best results have not yet been obtained. In Europe a 15 per cent saving in coal is not considered extraordinary because they obtain every day a saving of from 25 to 30 per cent on passenger runs as well as freight runs, and after a while with little effort we will do the same. In Europe a higher degree of superheat is used, while we are working with a superheat of about 150 to 200 deg. Herr Schmidt recommends at least 300 deg. and more, as long as the valves and the cylinders can be lubricated. In order to obtain perfect lubrication, he used forced feed which in my opinion is proper and correct.

H. H. VAUGHAN I am glad to see Mr. Toltz's endorsement of the principle of superheating, but I regret that I omitted to mention the engines in service on the Great Northern and the Northern Pacific. The figures given were compiled from replies to a circular letter sent out to all the roads in the United States and Canada and the omission occurred because no replies were received from those two roads.

2 In connection with the reliability of the figures, at some points on the Canadian Pacific Railroad coal is weighed, and at others it is measured, but I consider that the weight given is reasonably correct; at any rate our conclusions agree almost exactly with those which Mr. Toltz gives from exact weights on the Great Northern, so that if his results are correct, those on the Canadian Pacific Railroad are not very far wrong.

3 After one year's experience we made exactly the same statement that Mr. Toltz has made in connection with dampers as the deterioration in the pipes was not apparent until after one or two year's service, but after three years' experience we found that it is absolutely necessary to keep them up. However, the experiments which are being tried by Mr. Toltz will be very interesting.

4 It is difficult for me to believe all the reports of the large saving

experienced abroad, as certainly no experiments so far conducted here show any such saving, and I think that other factors besides the introduction of superheating have led to the reported results.

5 I also cannot agree with Herr Schmidt that forced lubrication is necessary, as our experience has proved distinctly that the oil can be delivered just as satisfactorily with the sight feed lubricator as with the force feed, and if this is done no other system can do more.

No. 1157

ANALYSIS OF LOCOMOTIVE TESTS

A. Hirn's Analysis of the Pennsylvania Railroad's Locomotive Test Conducted at St. Louis in 1904

By PROF. SIDNEY A. REEVE, WORCESTER, MASS.
Member of the Society

The following analyses were made in an attempt to ascertain what proportions of heat developed within a locomotive boiler were absorbed by the earlier and later portions of the heating surface, or by fire-box and tubes, respectively, or were lost up the stack. The St. Louis tests apparently furnish the best possible basis for such an investigation.

2 These analyses have been applied to the tests of only five out of the eight locomotives reported upon at St. Louis, because by the time that had been done, it had become plain that discrepancies too great to be handled by anyone other than those personally acquainted with the tests were involved. For the same reason, and also because the investigation was begun from mere professional curiosity rather than with any responsible aim in view, the laborious computations have been checked only in spots. The general consistency between the five different series of analyses was relied upon to indicate little probability of error.

3 Further inaccuracy is due to the discrepancy existing in the reports between the chemical analyses of the coal and of the flue gases. The figures given in the following tables for the percentages of surplus air present in the furnace, and for the weight of flue gases passing to the stack per pound of dry coal burned, must be open to question to the extent of about one tenth of their values. None of these inaccuracies applying to individual values, however, seriously affect the conclusions which are enforced by the analyses.

4 The essential boiler dimensions of the five locomotives, the tests of which are analyzed below, are these:

Presented at the Indianapolis Meeting (May 1907) of The American Society of Mechanical Engineers, and forming part of Volume 29 of the Transactions.

Locomotive No. 1499: Pennsylvania simple consolidation (2-8-0).

Grate area	49.2	square feet
Heating-surface: fire box	166.4	square feet
Total	2482	square feet
Ratio of heating surface to grate area	50.5	

Locomotive No. 734: L. S. & M. S. simple (2-8-0).

Grate area	33.8	square feet
Heating surface: fire box	218.9	square feet
Total	2541.2	square feet
Ratio of heating surface to grate area	75.2	

Locomotive No. 585: Michigan Central two cylinder cross compound (2-8-0).

Grate area	49.4	square feet
Heating surface; fire box	165.7	square feet
Total	2819.2	square feet
Ratio of heating surface to grate area	57.1	

Locomotive No. 535: A., T. & S. F. four cylinder balanced (Vauclain) compound (4-4-2).

Grate area	48.4	square feet
Heating surface: fire box	220.3	square feet
Total	2902.0	square feet
Ratio of heating surface to grate area	60.0	

Locomotive No. 3000: N. Y. C. & H. R. four cylinder balanced (Cole) compound (4-4-2).

Grate area	49.9	square feet
Heating surface, fire box	151.7	square feet
Total	3000.0	square feet
Ratio of heating surface to grate area	60.1	

5 The tables and diagrams herewith give the result of the analyses. Each table or diagram presents the variation of the distribution of the heat available from each pound of dry coal burned, to its various possible destinations in the boiler, in terms of a varying rate of combustion and boiler load. The five series of tests agree remarkably in pointing the following apparent results of increasing the draft, rate of combustion and boiler load from a moderate to an extreme degree, viz:

a Constancy, or only slight increase, in the heat lost up the stack;

b Constancy, or only slight increase, or possibly a slight decrease, in the heat absorbed by the tubes;

c Marked decrease in the amount of heat getting to the steam otherwise than through the tube surface, or supposedly by radiation through the fire-box walls;

d Marked increase in the heat not accounted for by the test.

6 The only heat destination not computable from the data supplied in the reports is the external radiation. This, from the nature of an internally fired well lagged boiler operated under constant steam pressure, is naturally (*a*) very slight and (*b*) constant for all boiler loads. Reduced to the terms of the diagrams or per one pound of

TABLE 1 LOCOMOTIVE No. 1499

Test number	Rate of combustion	Surplus air Per cent	Weight of flue gases per 1 lb. of dry coal Pounds	Boiler horse power	Boiler efficiency Per cent	Heat apparently radiated through fire box Per cent	Heat apparently lost up the stack Per cent	Heat not accounted for by the test Per cent
110	22.7	73.5	19.10	373	78.9	50.7	16.1	2.0
111	27.8	58.8	17.56	445	77.5	50.5	15.4	6.0
109	42.6	56.8	16.55	533	62.9	27.7	14.6	16.0
103	42.4	51.1	16.64	596	67.2	37.0	13.3	12.4
112	56.2	37.1	15.53	662	55.9	27.5	15.2	16.5
102	66.5	44.3	15.40	707	53.4	15.6	16.0	23.1
105	77.8	52.6	17.15	797	47.0	28.0	17.3	25.2
116	71.5	32.8	14.01	807	55.5	30.0	15.8	12.0
118	70.1	30.2	14.30	815	53.1	28.0	14.0	15.4
101	86.4	38.6	15.79	817	45.3	11.6	17.2	22.0
115	82.1	21.0	13.41	867	50.6	21.5	14.8	15.6
117	84.6	69.2	18.68	891	48.7	15.6	20.0	16.0

coal burned, therefore, it should stand as a small quantity, decreasing in proportion as the rate of combustion increases. It must fail completely, therefore, as an explanation of the increasing proportion of heat unaccounted for by the test under the heavier boiler loads.

7 The results shown are so surprising as to be, to the writer, incredible. In Locomotive No. 1499 the load is varied by 239 per cent and the rate of combustion by 372 per cent. In consequence, the efficiency drops from 78.9 to 48.7. Why does it do this? Where does the lost heat go? One would naturally reply, "Up the stack, because under heavy load there is no longer sufficient heating surface to absorb it." But the observed smoke box temperatures show

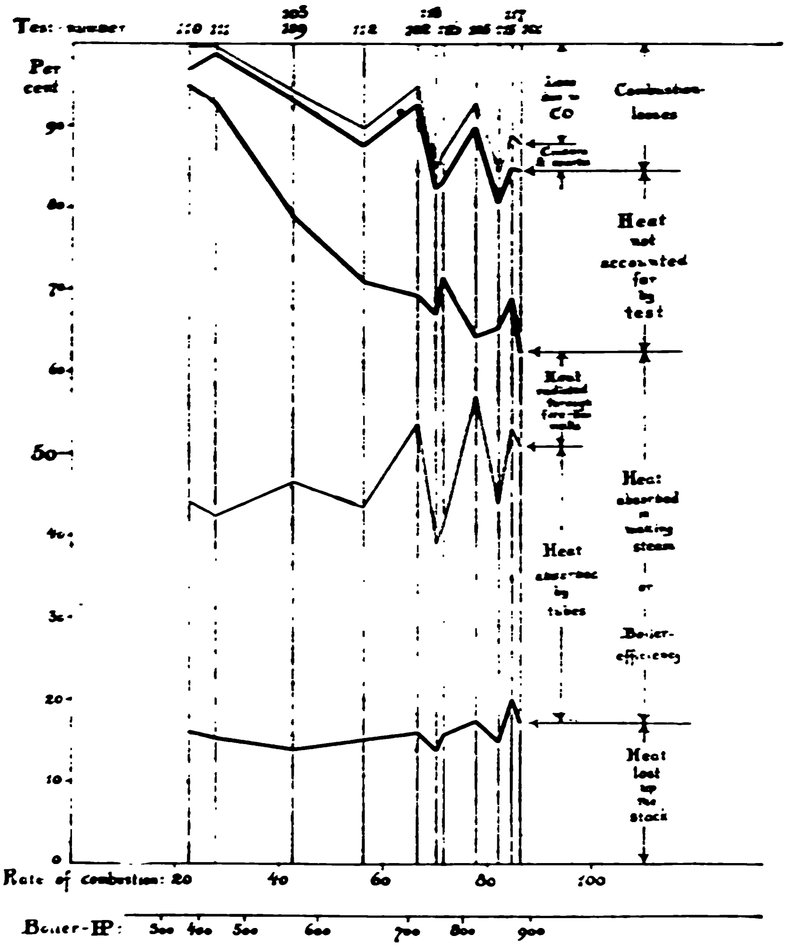


FIG. 1 LOCOMOTIVE No. 1499

almost no increase in the loss in this direction. This fact has already been pointed to as an indication of how efficient the locomotive boiler is under forcing. But if so, where is the efficiency? The locomotive engine has long been pointed out as a remarkably efficient power plant. How far this contention may be supported on the engine side of the question by the St. Louis tests I have not yet investigated; but it is certain that they show the locomotive boiler part of the power plant to be a pretty poor sort of an affair, except when run under very light loads.

8 In stating the above it has not been said that locomotive designers are to be blamed for not turning out a more efficient type of boiler.

TABLE 2 LOCOMOTIVE No. 734

Test number	Rate of combustion	Surplus air	Weight of flue gases per 1 lb. of dry coal	Boiler horse power	Boiler efficiency	Heat apparently radiated through fire box walls	Heat apparently lost up the stack	Heat not accounted for by the test
		Per cent	Pounds		Per cent	Per cent	Per cent	Per cent
201	32.8	70.1	21.32	322	65.2	17.1	15.6	16.0
202	41.8	64.7	20.51	439	71.3	23.1	15.5	8.6
205	52.7	69.5	21.12	489	61.4	11.6	17.5	14.9
203	60.0	52.4	19.00	539	58.6	14.2	14.7	19.2
206	80.8	35.3	17.19	683	56.3	18.4	15.1	20.0
209	101.7	43.2	18.25	776	50.3	10.15	16.5	24.4
220	117.0	33.7	17.41	820	45.5	−1.6	15.9	31.1
219	120.8	36.5	18.32	832	45.0	−1.7	17.1	30.1
210	121.3	51.2	21.30	832	45.6	−9.2	20.3	24.8
208	123.0	34.2	17.65	854	46.2	2.3	16.7	29.3
213	133.4	34.7	17.75	861	42.6	−2.6	17.3	31.4
212	139.0	30.6	17.56	887	41.7	−0.9	16.8	33.8

Under the peculiar conditions of operation which prevail with locomotive boilers, and particularly when forced, the efficiencies recorded may be regarded as a very creditable showing. But it should not be disguised that the performance of a locomotive boiler when forced is a heavy discount from what the same boiler does when steaming slowly. These discounts in efficiency are shown in Table 6.

9 My personal belief is that these efficiency figures are correct, and that the heat is lost up the stack to a greater degree when the boiler is forced than when steaming easily. Indeed, I believe that the stack loss is the chief explanation of the decreasing efficiency under forcing. My reasons for this position are:

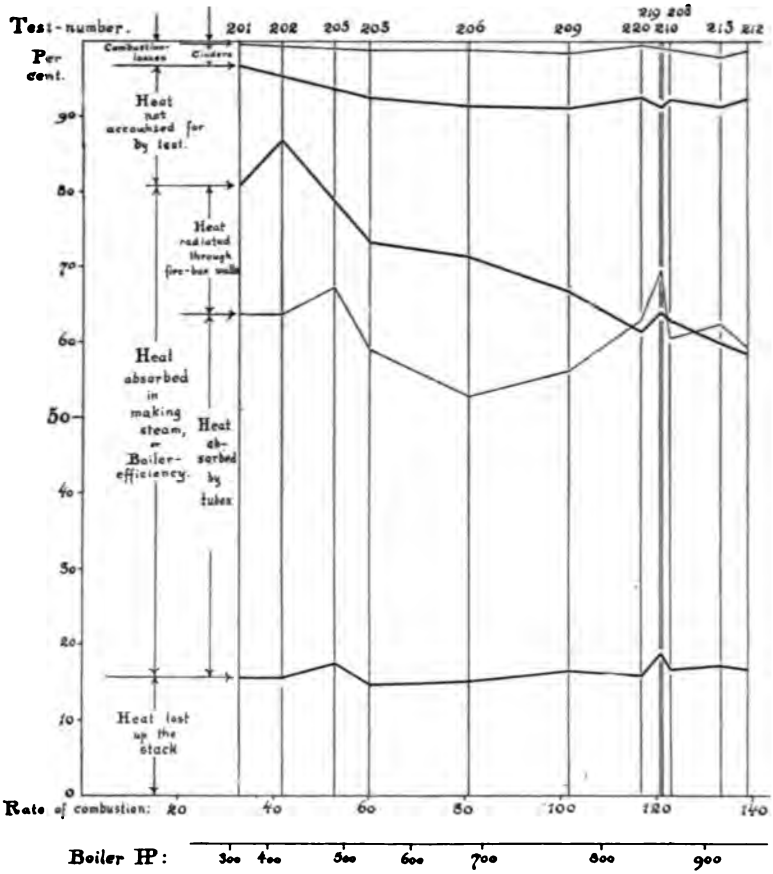


FIG. 2 LOCOMOTIVE No 734

a It is what is naturally to be expected;

b My little faith in the pyrometer as an instrument of precision, particularly when temperatures rise to the point where radiation begins to be as active as conduction;

c The unquestionably greater accuracy of the instruments relied upon for determining the other heat quantities recorded;

d The way in which this assumption solves this entire riddle. For if the stack loss of the diagrams be imagined as increasing with the load, instead of remaining constant, the incidental conclusions would be that

TABLE 3 LOCOMOTIVE No. 585

Test number	Rate of combustion	Surplus air	Weight of flue gases per 1 lb. of dry coal	Boiler horse power	Boiler efficiency	Heat apparently radiated through fire box	Heat apparently lost up the stack	Heat not accounted for by the test
		Per cent	Pounds		Per cent	Per cent	Per cent	Per cent
301	20.8	97.5	20.7	324	70.4	43.7	14.1	10.3
302	20.5	99.5	22.3	346	76.9	42.4	15.0	2.9
303	21.7	105.5	22.4	373	78.4	43.7	15.9	2.7
306	34.0	41.1	15.8	527	70.4	56.2	11.4	11.5
305	35.8	48.1	16.4	586	74.1	60.7	13.1	9.0
308	42.2	45.3	16.3	651	69.0	49.8	13.0	13.4
317	49.4	91.3	21.2	711	64.6	25.4	18.4	9.3
312	54.4	65.5	16.8	727	60.3	32.3	15.0	18.2
309	51.8	50.3	17.1	739	64.2	43.5	14.2	16.5
318	55.4	49.1	16.9	779	63.2	37.0	15.3	12.4
319	53.4	59.3	17.8	793	67.4	48.4	15.8	11.2
313	56.0	53.8	17.1	799	64.3	49.4	14.1	17.2

1 the heat unaccounted for would remain a small constant for all loads, and

2 the heat reaching the steam from each pound of coal would be divided between a decreasing proportion coming through the fire box walls (for the gross fire box radiation must be fairly constant for all loads above an insignificant one) and an increasing proportion coming through the tubes, the further ends of which are well heated only under a high rate of combustion.

Nevertheless, the man who has only the printed records to go by may not be too didactic in his conclusions. Having pointed out the facts,

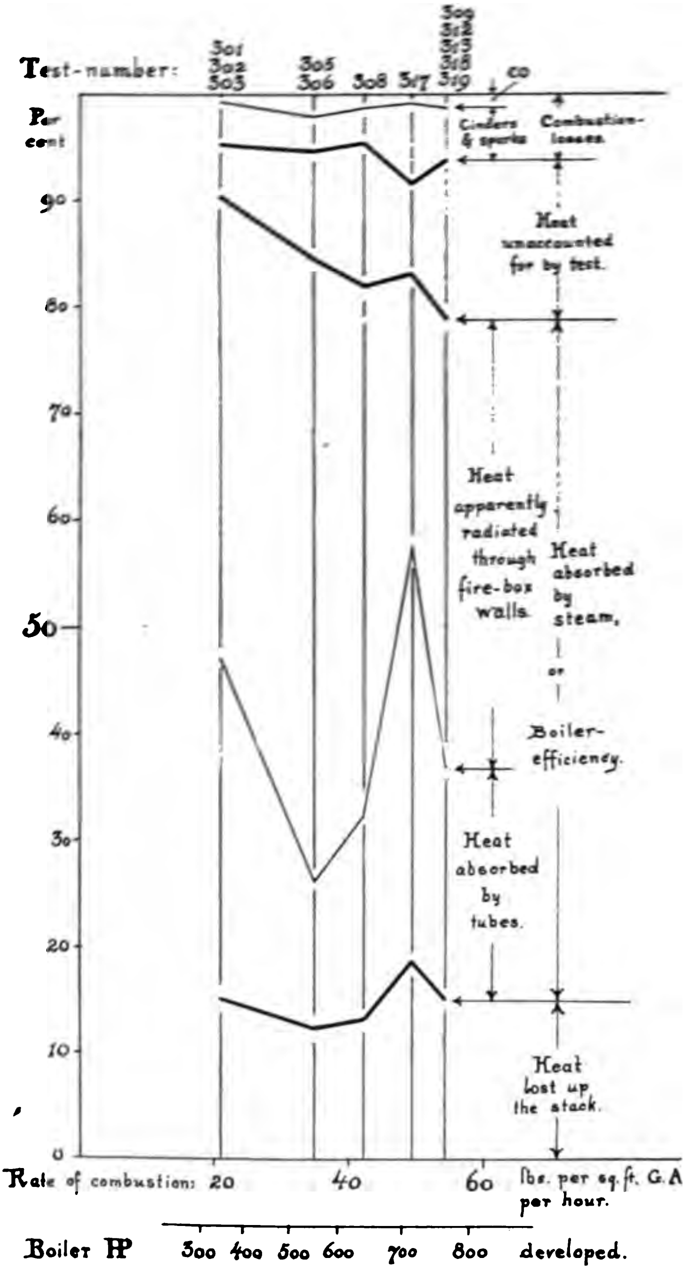


FIG. 3 LOCOMOTIVE No. 585

the explanation may well await their discussion by the gentlemen who were engaged in the work.

10 One conclusion may be published dogmatically and emphatically, however; and that is that if these Hirn's analyses had been made at the time of working up the results of the tests for publication, there would not have been the present uncertainty as to the value of these tests. The heat unaccounted for would have been noted, and those familiar with the ground would have been able to chase and capture the discrepancy. The engineering profession should lay down the rigid law, as a matter of mere labor saving, time saving and value of result, that no boiler test has been acceptably reported until it has been subjected to a Hirn's analysis, and that no engine test has been acceptably reported until it has been subjected to an entropy-temperature analysis to the same end.

TABLE 4 LOCOMOTIVE No. 535

Test number	Rate of combustion	Surplus air	Weight of flue gases per 1 lb. of dry coal	Boiler horse power	Boiler efficiency	Heat apparently radiated through fire box	Heat apparently lost up the stack	Heat not accounted for by the test
		Per cent	Pounds		Per cent	Per cent	Per cent	Per cent
601	18.1	91.4	21.3	309	78.4	44.4	15.0	3.6
602	24.2	73.3	19.5	377	71.1	34.6	14.5	11.5
603	28.5	68.3	18.8	453	73.6	35.3	14.7	9.1
604	42.6	76.6	19.9	600	64.5	21.6	16.3	15.3
605	42.5	78.6	19.6	612	66.2	25.7	16.4	14.7
606	51.0	59.4	17.9	721	65.0	28.1	15.5	17.1
607	67.4	58.0	17.6	896	62.4	22.9	16.5	18.1
609	92.0	62.1	18.5	1005	50.1	11.0	17.5	25.1
613	105.5	39.8	16.3	1086	47.3	6.7	16.2	28.7
160	120.6	39.6	15.9	1146	44.0	7.9	16.2	30.2
611	117.9	62.5	18.4	1187	46.1	1.9	19.0	27.6

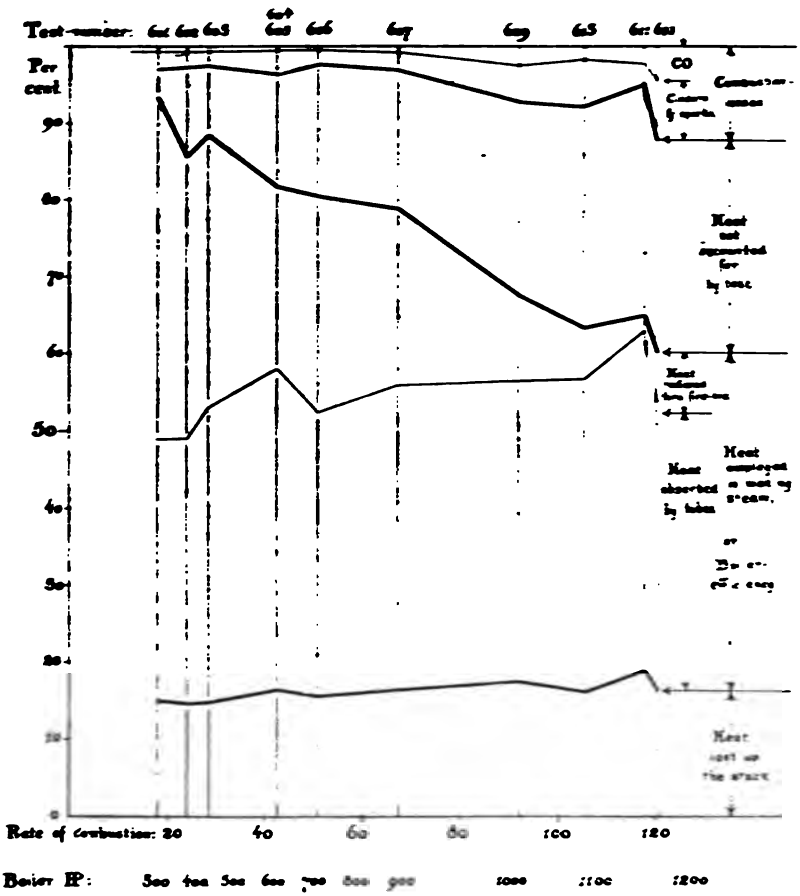


FIG. 4 LOCOMOTIVE No 535

TABLE 5 LOCOMOTIVE No. 3000

Test number	Rate of combustion	Surplus air	Weight of flue gases per 1 lb. of dry coal	Boiler horse power	Boiler efficiency	Heat apparently radiated through fire box	Heat apparently lost up the stack	Heat not accounted for by the test
		Per cent	Pounds		Per cent	Per cent	Per cent	Per cent
801	25.8	70.0	19.0	436	75.3	33.7	14.2	8(?)
802	35.0	66.0	18.6	542	69.0	26.4	14.6	13(?)
805	47.2	67.5	18.9	697	65.3	16.3	16.5	15.5
809	60.6	53.9	17.5	868	63.9	25.9	16.5	17.0
806	62.4	48.9	16.9	903	64.1	25.0	16.2	15.0
813	69.6	44.9	16.3	958	61.7	26.4	15.6	19.2
814	77.9	62.5	18.5	1093	62.1	14.5	18.8	14.4
815	98.8	49.8	16.8	1130	51.0	9.9	17.3	27.4
807	116.2	46.0	16.5	1156	53.0	14.1	16.8	27.3
811	116.2	54.6	17.4	1297	49.8	4.3	19.2	27.6
812	134.2	40.4	16.1	1421	46.9	5.1	18.3	32.5

TABLE 6

Locomotive	Percentage increase in		Discount from best efficiency
	Rate of combustion	Boiler power	
No. 1499	372	239	42.6
No. 734	424	275	40.2
No. 585	269	247	23.1
No. 533	652	384	43.99
No. 3000	520	326	37.7

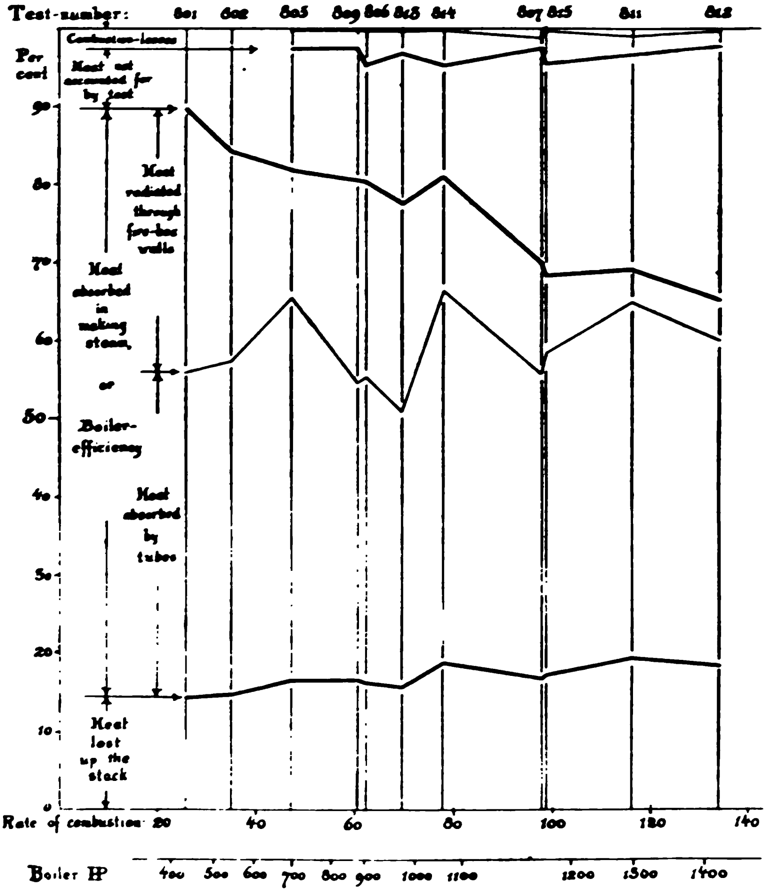


FIG. 5 LOCOMOTIVE No. 3000

DISCUSSION

PROF. W. F. M. GOSS In so far as Professor Reeve's paper appears to be offered in criticism of the Society's Committee, which was associated with locomotive testing at St. Louis, I wish to say that, in my opinion, there is no just ground for such criticism. This statement is emphasized by the fact that Professor Reeve has gone outside of the report of the Society's Committee and has taken data from other sources upon which to base his arguments.

2 As to the real merits of his discussion I would add that those who have studied the locomotive problem well understand that the efficiency of the machine diminishes as the power developed increases. That quantity which he designates as "unaccounted for loss" is not so in fact. It is, chiefly, though not entirely accounted for in the unconsumed fuel which is discharged from the stack. In planning the tests by the Pennsylvania Railroad Company it was sought to provide for all data necessary to a complete heat balance representing the action of the locomotive boiler, but the problem in locomotive service is difficult and it was discovered that the means by which it was sought to secure such results were insufficient. As a consequence, while a large amount of data bearing upon that general problem was accumulated none of it has been published. The principal difficulty centers in the sampling of the smoke box gases and in securing an accurate measure of the fuel losses in the form of sparks.

3 May I be permitted to add, that my experience in testing locomotives has convinced me that the most difficult part of the whole process is that of sampling smoke box gases. Many different plans have been tried and have proved insufficient. I am glad to announce, however, that there will soon issue from the Purdue laboratory data covering 25 or 30 tests which are consistent and complete with respect to the smoke-box gases. These will probably constitute the only series of facts which, up to this time, have been developed in locomotive service supplying an accurate measure of all the quantities which go to make up the losses which Professor Reeve emphasizes as unaccounted for.

PROF. WM. KENT The paper does not give the data from which the results shown in the diagrams were computed, but these data probably include the ordinary analysis by the Orsat instrument of the composition of the chimney gases, giving only CO_2, O, CO, and N by difference, taking no account of hydrogen or hydro-carbons. A large part of the heat not accounted for is probably due to the hydrogen or hydro-carbons that pass away unburned. Hydrogen may be formed in a furnace by the decomposition of the moisture in the coal.

2 With forced driving, the size of the combustion chamber is not large enough to secure the complete burning of the smoky gases. These gases enter the tubes at a lower temperature than they would if they were thoroughly burned. This may account for the fact that the heat absorbed by the tubes is no greater with rapid than with slow driving.

3 I would like to know what authority there is for calling the heat balance in connection with a boiler test a "Hirn analysis," and to be referred to any book in the English language where a Hirn analysis for a boiler test is described. All the references to Hirn's analysis that I have show that it is applied to steam engines and not to boilers. The author of the paper says that if this Hirn's analysis had been made at the time of the working up of the results of the tests, the heat unaccounted for would have been noted and those familiar with the ground would have been able to "chase and capture the discrepancy." I have never yet seen any report of a boiler test with Western coal in which the heat unaccounted for has been "chased and captured," although the heat balance was made immediately after the test, for the reason that I have never known of a boiler test in which the hydrogen and hydro-carbons escaping into the stack were determined by analysis. We will not be able to "chase and capture" the discrepancy until we have better means of obtaining a correct average temperature of the escaping gases and correct methods for determining the hydrogen and hydro-carbons, when they amount to, say, only one or two per cent of the total volume of the chimney gases.

The Author In reference to Professor Goss' statement that the paper "appears to be offered in criticism of the Society's Committee," it should be replied that such was not at all the author's intention. His primary object in submitting the paper will be referred to later. It was quite as an incident to this that he found occasion to call attention to the insufficiency of present methods of reporting tests, which are habitual with many engineers besides those concerned here. Since the official report published by the Pennsylvania Railroad Company presents the results of these tests in a form which quite fails to bring out their chief significance, it would seem inevitable that the method of report should come in for criticism. But no attempt has been made to locate responsibility for the lack, and no desire has been felt to insinuate further fault than a failure to reform the defective methods of the past.

2 Nor is the question one as to the possible accuracy of observation of evasive quantities, as Professor Goss' words would indicate. It is a question of so reporting the results that it becomes obvious that quantities which could not be measured were not measured.

3 The way in which the paper originated shows this: A prominent locomotive designer wrote to me calling my attention to the very slight waste of energy up the stack, as shown by these St. Louis tests. At first reading of the St. Louis report it appeared that the gentleman was right. It appears now that he was deceived. Professor Goss and Professor Kent both say, in effect, that he was. They say that sparks, hydrocarbons, etc., were escaping up the stack in profusion, under heavy load, and that it was impossible to measure them. But nowhere in the report is any such a statement to he found. Nowhere appears a caution that the heavy power tests must be discounted in accuracy to whatever degree the reader may attach to a 30 per cent failure to balance. Nowhere appears a caution that this discount applies to every test in a different degree. On the other hand, specific and accurate statements of both sorts of stack-losses, in sparks and in chemical composition, are found, refined to decimal places. If they are worthless for the only purpose to which an engineer might put them, to the egregious degree shown by the analyses, why does not the report say so? The report is responsible for widely spread wrong inference as to the degree to which it illuminates locomotive-action, and criticism of a constructive sort is not out of place.

4 If it takes such a laborious analysis as these heat-balances to bring out the elementary significance of these results, why is it such an untoward thing to demand that such analyses be regarded as a standard part of the clerk's duties in reporting any and every boiler-test?

5 Both Professor Goss and Professor Kent, in their second paragraphs, speak of the unaccounted for heat of a locomotive boiler test as if its destination were quite a settled fact. Yet each of them says, in his final paragraph, that it is as yet quite impossible to determine its destination. If Professor Goss' forthcoming reports upon his investigation of this question really are to constitute our first knowledge, why is not this paper, calling attention to the great lack, a natural and acceptable preface thereto?

6 The question as to the hydrogen escaping undetected in the flue-gases, which Professor Kent mentions, was carefully investigated in a large number of the tests. The results were fairly consistent with each other, but not with the remainder of the data published. The

paper makes mention of this. If this is the explanation of the lost 30 per cent of the heat, the report should have stated the fact plainly and prominently. Enough care was taken, and enough space in the report devoted to provision against minor errors of 1 per cent or less, to make this default of over 30 per cent indefensible.

7 But all of this is incidental merely. The prime object of the paper was to bring out the fact that, in this day of striving after enormous powers and train loads on our railroads, a loss of power amounting to several hundreds of horse power in a single locomotive remains apparently overlooked and unexplored. For if the importance of this fact had been grasped, if even the fact itself had been known, it is fair to assume that the locomotive engineers of the country would have been centering their interest upon it, the locomotive periodicals would have contained frequent reference to it, and the St. Louis tests would have been directed primarily toward the doing of this very "chasing and capturing" which Professor Kent so derides as impossible and Mr. Goss says he has done.

8 I very much regret, that the paper has elicited no discussion whatever of this main question, namely, the desirability and feasibility of so designing our locomotives that the stack-losses, or whatever they may be, may be lessened at heavier loads, even if they are thereby made greater at light loads. If the trouble lies in the incomplete combustion of the hydrocarbons, due to insufficient firebox space, then it would seem profitable to burden the locomotive with an exaggerated combustion chamber. If it be due to the objection of solid unburned fuel, there must be some remedy for that. If it be due to high stack-temperatures, as I judge from the discussion is still an open question, then it will be profitable to burden the machine with a corresponding suitable remedy.

9 It does not seem that locomotive designers are concerning themselves deeply over ways and means to any of these ends, except possibly the first. In view of the facts, it would seem profitable to inquire why this is so.

10 The conclusion of prime importance, however, is that our heavy locomotive should possess a better efficiency when forced. It is not that fuel will be saved, but that heavier trains can be hauled. If the boiler of Test 812 had had the efficiency actually attained by the boilers in Tests 110, 303 or 601 there would have been available for traction a round thousand horse power more from the same fire box and fire than was actually gotten. It is idle to reply that this is impossible. Of course it is, to get all of it. But if even half of this thousand horse power could be saved, the gain in trainloads would be

enormous. And at present we are not trying to save it. We are plainly designing for maximum efficiency at quarter load.

11 Then there is the fuel consideration, after all. Take locomotive No. 535. Suppose that it usually operates one-quarter of the time at 300 h.p. and 78.4 per cent efficiency; one-quarter of the time 600 h.p. and 64.5 per cent efficiency; one-quarter of the time 900 h.p. and 62.4 per cent efficiency, and the remaining quarter at 1150 h.p. and 44 per cent efficiency. Its mean effective efficiency is 57.6 per cent. Suppose, on the other hand, that the boilers were so designed as to have efficiencies, under these four loads, respectively, of 44, 62.4, 78.4 and 64.5 per cent, the same efficiencies as actually attained, but differently arranged in terms of load. The mean effective efficiency would then be 66.3 per cent, meaning a saving in fuel-bills of 13 per cent. It certainly seems as if this might be accomplished.

12 The one point which the writer wishes to emphasize is the large amount of power—from 500 to 800 h. p.—which these locomotives would have been able to develop from the *fire they were actually able to maintain* over and above the maximum power developed had they been designed to develop their maximum efficiency at higher rather than at lower loads. A jump in maximum boiler capacity *from present size of fire* from 1400 to 2000 h.p., which is what these St. Louis tests offer us for correct design, is a big matter, even if we get only a part of it.

13 The heat designated as absorbed by the firebox is computed by taking the difference between the heat absorbed in steam making, which is probably one of the most accurate in the tests, and the heat apparent in the temperature range between fire box and smoke box, which is presumably that absorbed by the tubes.

No. 1158

MATERIALS FOR THE CONTROL OF SUPER-HEATED STEAM

M. W. KELLOGG, NEW YORK, N. Y.
Non-Member

GENERAL

Since the introduction of superheated steam as a large factor in economy in stationary power plant use, the question of what type of material is best for the proper controlling of the resulting high temperatures has caused a great deal of investigation and interest.

2 In the following discussion of materials, some reasons will be given which are the results of experience and test, and other facts which we have accumulated from reliable sources will be shown. This article treats particularly of what might be called in a general way piping systems, which systems are made up of pipe, fittings, valves, and the necessary details connected therewith, such as joints, gaskets, etc., and are taken up separately.

PIPE

3 There can be little question as to the matter of pipe except quality. Of course, welded wrought iron or steel pipe is successful, but the difference in the quality of pipe under different conditions is very material. As in nearly all instances in a superheated steam station the old fashioned screwed joint is not satisfactory, it is necessary to do what is termed "work" the pipe—that is, weld, van stone, etc.—to make either a welded, van stone, or other joint of the same general description.

4 The accompanying cut is what is known as a "van stone joint."

5 For this work, the pipe made from open hearth steel is a great deal the best for manufacturing reasons, because it can be properly "worked," there being less carbon, and the quality is much more uniform. Bessemer steel pipe will very often act in a satisfactory man-

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mer, but one is never sure that Bessemer will run even and, therefore, troubles may result.

6 It is practically impossible to "work" wrought iron pipe. In making what is known as a "van stone joint," the pipe is nearly sure to split very badly, not only at the weld but all around its outer circumference

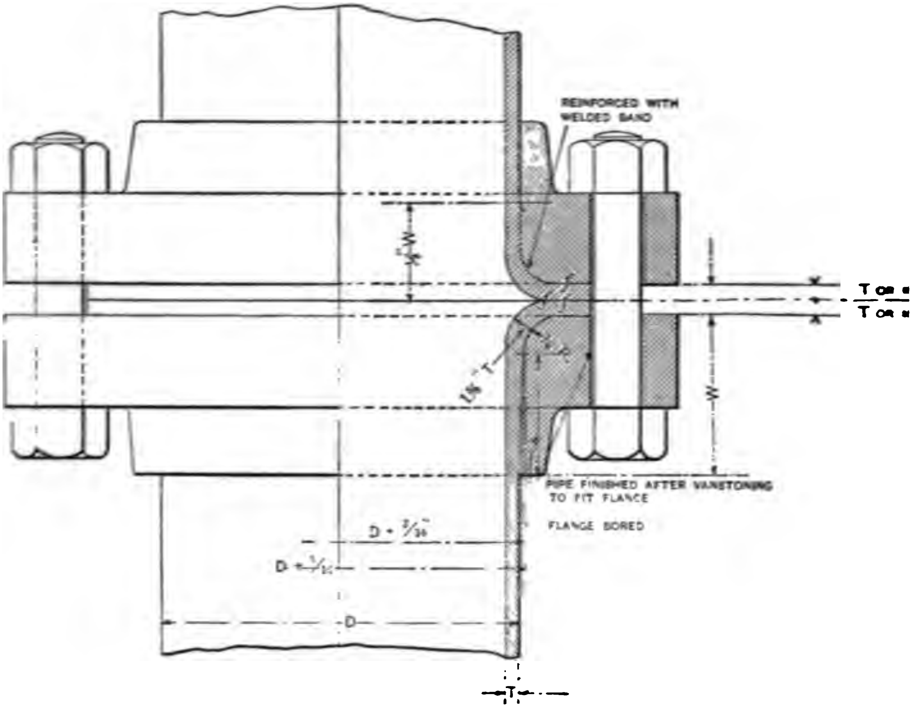


FIG. 1 VAN STONE JOINT

7 Nearly opposite qualities from those used for getting good results from "working" pipe are required for threading. A good quality of wrought iron will cut and thread more easily with standard pipe machines and standard dies than a steel pipe, and a Bessemer steel pipe will thread much more easily with standard dies than open hearth.

8 A great many manufacturers have difficulties in threading open hearth steel pipe, for the reason that they set the dies exactly the same as if they were cutting other qualities. This causes ripping of threads, etc. The die in a pipe machine should be set at a greater angle, with the radius of the pipe passing through the point of contact

of the die for soft steel, than it would be for other kinds, and this in itself will very often eliminate great troubles in this line. The question of lubrication, etc., is also important.

9 The ordinary commercial pipe will stand more pressure than the average person believes. A standard 1 inch piece of welded pipe will usually not break under 1600 pounds per square inch hydraulic pressure.

10 Full weight pipe, I believe, is perfectly suitable for any temperature and any working pressure up to 225 or 250 pounds, as long as it is not thinned at any point by cutting and threading.

FITTINGS

11 The design of fittings as generally manufactured for the different purposes are, in a general way, very satisfactory, with the one

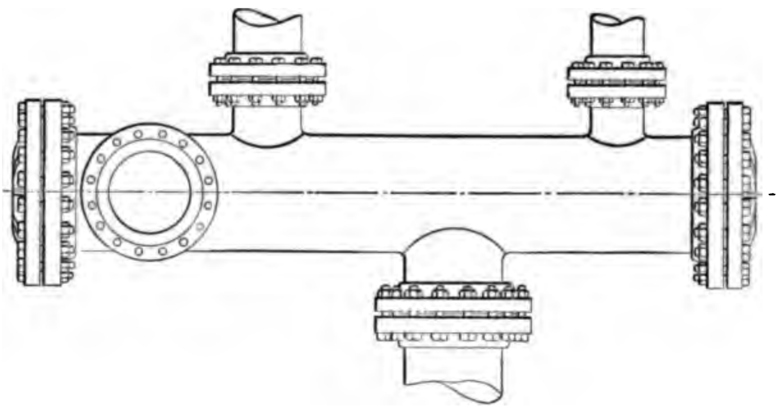


FIG. 2 WELDED WORK

exception that very few manufacturers on their standard articles include what is known as the "long fillet" between the body of the fitting and the flange. This is a very desirable point, due to the fact that at this place there is the greatest strain from shrinkage in the molds, which also tends to develop porous spots. Many large users of this type of material have learned this thoroughly and design their fittings specially; the chief difference in their design from that of the general manufacturer merely covering this point. The quality of the material in fittings, however, is a very important thing in connection with superheated steam.

12 The latest practice is to do away with fittings entirely on high pressure steam lines and put what are known as "nozzles" on the

piping itself. This is accomplished by welding wrought steel pipe on the side of another section, so as to accomplish the same result as a fitting. In this way rolled or cast steel flanges and a van stone or welded joint can be used. This method has three distinct advantages, to wit:

a The quality of the metal used, for reasons explained hereafter when the subject of the effect of heat on metals is taken up.

b The lightening of the entire work.

c The doing away with a great many joints.

13 As a general average, at least 50 per cent of the joints can be left out, and sometimes this proportion runs up as high as 60 or 70 per cent, according to the layout of the system.

14 If this method is employed, substantial welds must be made, not only to stand the pressures required but also the strains; this is accomplished successfully in Germany, England, and the United States.

VALVES

15 It is important to have a good design of valve. I believe that nearly any of the designs made by the good manufacturers are entirely suitable, such as a broken or solid wedge valve of the ordinary type, under the condition that all machine work is done thoroughly and the quality of metal used is satisfactory for the purpose intended.

16 It may be interesting to note here the effect of a large range of temperatures on a short piece of steel. By calculation, a piece of steel six inches long, heated 500 degrees, will expand 0.019 inch. This figure is put down to show how variations in the coefficient of expansion of metals by heat have a large effect on the permanency of a valve staying tight, and it can readily be seen that a small proportion of the distance given is sufficient to cause trouble.

METALS

17 I find that different authorities vary slightly in their statement as to what temperatures different metals will stand with good results. German authorities state that cast iron should not be used above 480 deg. fahr. Other authorities allow us to go as high as 575 deg. fahr. Above these temperatures in cast iron the limit of elasticity is reached with a pressure varying from 140 to 175 pounds. Under such conditions the material is strained and does not resume its former shape, and eventually shows surface cracks, which continue to grow until it lets go. These temperatures and pressures also lead in time to a

shrinkage of all parts, and to a structural alteration of the metal, which results in leakages in valves at the seatings. Therefore, it would seem that iron castings are unsuitable for both fittings and valves to be used in any superheated steam work. While they may last for some time, after a few years' use the metal becomes very weak and some cast iron reaches the point in weakness where if it were merely tapped lightly with a hammer it would break into pieces.

18 The only adaptable metal I believe to be cast steel. The results of tests on this metal by Bach for the effect of temperature are such that at 572 deg. fahr. the reduction in breaking strength only amounts to about 1.1 per cent and at 752 deg. fahr. to about 7.8 per cent. Therefore, it seems that this metal is practically capable of withstanding all pressures and temperatures up to at least 800 deg. fahr., without showing any appreciable weakness.

19 The influence of high temperatures on bronze, etc., is very material. At ordinary temperatures this metal has a breaking strength of about 34,100 pounds per square inch and an elongation of 36 per cent. At 572 deg. fahr. the breaking strength falls to about 19,500 pounds per square inch and the elongation to 11.5 per cent. At 662 deg. fahr., which is quite a common temperature as it leaves the superheaters, the breaking strength of bronze only amounts to 12,200 pounds per square inch and the elongation at the breaking point is only approximately 1¾ per cent. This seems to eliminate entirely brass or bronze of ordinary composition for use with highly superheated steam.

20 The effect of temperature on nickel is very similar to that of cast steel and in consequence this material is very suitable for use in connection with highly superheated steam. Bach recommends that bronze alloys be done away with for use on steam lines above a temperature of about 390 deg. fahr. Even neglecting the special quality of nickel seatings, on account of the great toughness of this metal and the methods which can be used for securing rings of this substance to the valves and conical surfaces, it has the special advantage of having the coefficient of contraction and expansion with temperature almost exactly the same as that of cast steel, so that no slackness of the rings occurs and the valves remain absolutely steam tight. There are instances in which valves constructed with nickel seatings have been satisfactorily used with steam temperatures up as high as 932 deg. fahr.

21 Seats, discs, and bushings made of brass or plain bronze do not retain their shape.

22 For spindles on superheated steam work I strongly recommend nickel steel, which holds its shape and does not deteriorate with high temperatures.

23 Seatings in valves should not only be screwed in but also pinned in addition, using a fine thread which is very long, to give a tight joint. Seats should also have a flange on the top that makes a joint with the body when screwed down, which prevents the tendency to leak through.

JOINTS

24 I think it is generally acknowledged that the old fashioned screwed joint, no matter how well made, would not be suitable for superheated steam work. This leaves for discussion two general types, viz: welded joints, and what are generally known as van stone or climax joints; that is, any joint where the pipe is turned over the face of the flanges.

25 In welding a flange on a piece of pipe, great care must be taken to see that the weld is perfect because of the unequal thicknesses of the metals to be so welded. If the weld is thoroughly made, this type of joint is very good, although for erection purposes, due to the fact that the flanges cannot swivel, it does not equal the turned-over joint as mentioned above. The manufacturing expenses in making a welded joint are also much more for the same type of work accomplished, on account of the necessity of doing all finishing work after all rough work, such as welding and bending, has been completed. Therefore the cost of welded joints is greater, not only for the work done but because of the increased expense in finishing on account of the necessity of employing methods different from those where the flanges, etc., were all finished before the joints were made, as is possible on the turned-over joint mentioned above.

26 In regard to the turned over or van stone joint, the quality of its manufacture seems to us the most important feature. This joint can be made in a careless way where the pipe is in no way thickened up and only faced on the front. A joint of this kind does not give good results, principally for two reasons:

a The thinness of the metal on the turned over portion; and

b On account of the recesses left between the back of the pipe on the turned over portion and the flange, due to the pipe not being finished at this point.

27 The writer believes, however, if this joint is properly made, it is equal to the welded joint as a manufactured article and superior to the welded joint as an article for erection.

28 To have this type well made, the pipe on the end should be thickened up in an amount sufficient so that after the joint is turned over there will be enough metal left to face the turned over portion on the front, on the outer edge, and on the back. We of course take for granted that the flanges are finished on the front. After the work above mentioned is done, the pipe should be as thick on the turned over portion as the original thickness, or very close to it. Increasing the thickness of the pipe on the end before going through the operation is done in several ways. In a general way, I consider any of the methods satisfactory. The point made of facing the turned over portion of the pipe on the back is an exceedingly important one, much more so than most people seem to realize. I have known instances where it has been found impossible to make a ground joint, for no other reason.

29 In reference to making up a joint, I believe that the face of all flanges or pipe where a joint should be made ought to be given a fine tool finish and have the face level, and then use a gasket of some description. A perfectly made ground joint is a good thing but it is very expensive, and it is hard to get the average contractor to furnish it in a perfectly workmanlike manner. Also, after it is so done, it is liable not to stay tight, on account of the tremendous expansion and contraction causing such strains that the joints are liable to open up, particularly when the pressure is taken off the plant. The simple expansion and contraction on the bolts that make up a joint would cause this.

GASKETS

30 There are large numbers of gaskets manufactured of all types and descriptions. It is very hard to take up this subject and be fair to each of the manufacturers, for the reason that practically no one has had experience with every type to judge for himself, and hearsay would lead us to suppose that all of them are at one time perfect and at other times useless.

31 I have used a great many different types of gaskets, however, and have obtained the best results with a corrugated soft Swedish steel gasket with "Smooth-on" applied, and with the McKim gasket, which is of copper or bronze surrounding asbestos. The ordinary corrugated copper gasket is a very popular make and has been used a great deal. On superheated steam, bad results usually follow. There seems to be some peculiar action that causes this, as on superheated steam lines a corrugated copper gasket will in time pit out in some part of the flange nearly through the entire gasket.

A great many reasons are given for the cause, such as electrical action, disintegration, etc.

32 The wear of a gasket depends largely on the method of pulling up bolts on flanges. In fact I believe that a great many troubles have occurred because of imperfect erection. If joints are pulled up entirely on one side and left loose on the other, and then taken up on that side, trouble with the gasket is almost certain. The bolts should be taken up gradually all around the flange. The experience of the erecting crews on high class superheated steam lines is an exceedingly important thing. The average steam fitter is not suited to this type of work. He has had experience with lower pressures and less important tasks and after a piece of work is erected by him it is customary to find a great many leaks which are usually only eradicated after the whole joint has been broken and properly repaired. All these troubles can be eliminated by using only steam fitters experienced in the type of work under consideration.

DISCUSSION

MR. J. ROWLAND BROWN There seems to be a growing tendency to get away from threaded pipe joints and adopt such types as the welded and the van-stone joints. On paper there seems to be no choice, as the threaded joint has three chances to leak to one in either of the other types. In most installations it is not possible to make either of the latter joints and the pipes with flanges must be shipped in from a distance after dimensions have been furnished. In most all localities it is possible to get pipe threaded up to 8 in. or 10 in. diameter. It is a rare case when boiler and engine connection flanges come exactly as shown on the plans, and for this reason at least one length should be made up in the field with screwed flanges so as to relieve the piping of unnecessary strains due to springing the pipe into place.

2 There are a great many high pressure plants using superheated steam in piping made up with threaded joints and giving perfect satisfaction. The piping must of course be extra heavy and the joints must be peined or rolled with a roller expander. Most leaky joints are due to careless erection and the springing together of pipes laid out from plans and not fitted up on the job.

3 I have experimented some with different gaskets and find that the method of installing them has more to do with success or failure than the type of the gasket. In superheaters connected for flooding an especially hard condition is met; that of having the joint sub-

jected alternately to superheated steam and water. I have had success with three kinds of gaskets. A gasket made of long fiber asbestos held together with an unusually small quantity of binding material, coated with graphite and subjected to heavy pressure, gave excellent results and withstood the high temperatures.

4 A joint made by grinding together a male and a female flange and then inserting a thin soft steel corrugated gasket covered with graphite and oil, seems to meet all conditions but must be carefully put together.

5 I have used a design of joint in which both flanges have grooves and a cast iron ring is ground to a seat on each of the flanges and then used as a gasket as shown in Fig. 1. In cases where the fittings are too large to be ground together this form of joint is especially valuable. Another advantage is that there are no male flanges which are liable to be injured in shipment or when lying around awaiting erection. The cast iron rings should be made in standard sizes and carefully boxed for shipment.

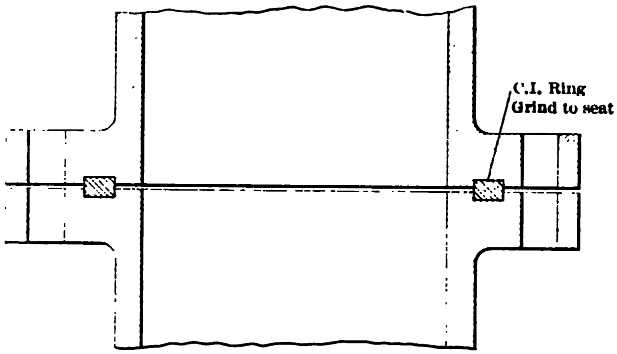


FIG. 1 GROUND JOINT WITH CAST IRON GASKET RING

6 When this joint is properly assembled it will stand the conditions present in flooding a superheater without any signs of leakage. In cases where it was necessary to spring the pipe in order to make up the joint it was found best to put a corrugated steel gasket on each side of the cast iron ring.

Mr. August H. Kruesi Referring to gate valves, Par. 15 of Mr. Kellogg's paper states the belief that "Nearly any one of the designs made by the good manufacturers are entirely suitable; such as broken or solid wedge valves of the ordinary type, under the condition that all machine work is done thoroughly and the quality of metal used is satisfactory to the purpose intended." In my opinion no gate valve is satisfactory for either superheated steam, or saturated steam unless it is used in the position for which it is designed; that is, in a vertical position with the hand wheel up. It can readily be seen that unless the valve is used in this position there is nothing to make the tapered plug seat true and parallel with the inclined seats. Experience shows that when it is required to shut steam off absolutely a globe valve or angle valve must be depended upon. Such valves can generally be tightly closed or, at any rate, made tighter than gate valves after a period of service, and when leaky, can much more readily be made tight again.

2 In designing new piping systems it is often possible to employ angle valves instead of elbows and thus dispense with gate valves, the angle valve offering very little more resistance to the flow of steam than an ordinary elbow.

3 Referring to Par. 17, I would place the permissible temperature for cast iron at a lower value. Tons of cast iron fittings have been scrapped after a year's operation at a temperature approximately the same as the figure mentioned by Mr. Kellogg. At the time they were installed, the fittings were believed to be the best obtainable, and they were extra heavy weight.

4 I go further than Mr. Kellogg, and state unequivocally that in my opinion cast steel is the only suitable material for cast fittings in large saturated steam piping at pressures of 150 lb. and more. This is an unusual statement, and doubtless will be challenged. It cannot be proved that cast iron is suitable because it has been in use for ten to twenty-five years. In these cases it just happened to be satisfactory or conditions may have been exceptionally favorable as regards steadiness of load, etc. In designing new plants a proper regard for the safety of operators and continuity of service requires a greater margin for contingencies which cannot be foreseen, than ordinary cast iron affords.

5 Referring to Par. 28, the method of thickening the pipe by welding a band around it, as shown in Fig. 1, is of doubtful utility on account of the uncertainty of such welds. Thickening the metal by upsetting it, wherever practicable, is certainly much to be preferred.

6 Referring to Par. 31, regarding corrugated copper gaskets, I can endorse that statement from long experience. The copper becomes inert, just like so much lead, and in my opinion the corrugated gasket has a serious fault in that it will pull up more on one side than the other, over-straining the bolts, and often the flanges, as a result.

MR. MAX E. R. TOLTZ In regard to the use of cast iron in connection with superheated steam, all the steam headers of the superheaters used on locomotives are of cast iron, and so far there has not been any trouble. The return bends of the superheater elements of the smoke flue superheater are made either of cast steel or malleable iron. In the joints of steam pipes we use copper gaskets and the longer they are in service the tighter the joints become. The valves for superheated steam should be of the globe type because gate valves will leak and are therefore unsafe. The valve of the poppet type is the best, especially when it is double seated.

THE AUTHOR I thoroughly understand that practically no engineers agree absolutely on the points under discussion, as well as on a great many other theoretical and practical points connected with superheated steam. I believe that discussion, however, is a very good thing, and it will gradually lead people to a more settled and universal opinion.

2 To substantiate my statements in regard to cast iron and in favor of cast steel for cast fittings in saturated steam piping, I know of places where cast iron body gate valves have been installed on about 200 deg. superheat and approximately 170 or 180 lb. pressure, and two years' after installation were $\frac{3}{8}$ inch longer face to face than when they were put on. This in itself is a proof that cast iron on high temperatures expands without contracting proportionally when it has cooled off.

3 An accident which killed several men happened on a superheated line in Washington about two years ago. There was a break in a cast iron screwed flange, I believe on a 20 in. piece of pipe. After the accident it was found that the flange could be slipped on by hand approximately 1 inch without any screwing, and it screwed up to the shoulder without a tight joint. At the time of the accident there was great criticism of the material and the manufacturers, but I believe decidedly that the whole cast iron flange expanded after installation and finally gave way. I mention these two illustrations more or less to back up my statements in regard to cast iron.

4 My statements in reference to surface cracks, etc., are the results of actual tests.

5 I did not wish to imply that the gaskets mentioned in my paper were the only suitable ones. I stated, and still state, that I have had the best results from those mentioned but do not wish to condemn in any way gaskets of the asbestos fiber type

6 In reference to joints, I think by all odds the best type of joint is the joint where there are raised faces on both flanges from the inside of the bolt circle to the inside of the axis of the pipe.

7 In reference to Mr. Kruesi's discussion, I agree with him that where steam is to be throttled and where the valve is to be used often, a globe type or angle type is better for lasting qualities in nearly every instance than a gate valve. I do not, however, agree with him that gate valves should never be used. I have found by observation and experience that globe valves, angle valves and elbows decrease the flow of steam and consequently the loss of pressure quite materially. I know of one plant installed where there was a loss of pressure between the boilers and engines of 15 lb., seemingly from no other reason than the great number of angle valves and elbows, the original steam pressure being 160 lb. and that applied to the engine 145 lb. The fact that this loss should have been due to the above reasons seemed practically impossible and therefore was investigated very thoroughly. I might, however, add that in the plant under discussion the pipe lines were too small.

8 I regret to note that Mr. Kruesi objects to reinforcing a vanstone joint by means of welding. I cannot say too much in favor of the matter of a very thick turned-over portion of pipe for vanstone joint work, to allow plenty of thickness after the joint is faced on the back. I believe that the method of increasing this thickness by welding to be even superior to the upsetting as mentioned by Mr. Kruesi.

9 Our experiments have shown that upsetting the pipe to an extent necessary to get material benefits from the thickening of the turned over portion is so hard on the pipe that it is apt to crystallize and weaken it. Welding a piece on in no way weakens the pipe, and there is no reason why a perfect weld cannot be obtained. I want further to state that the very objection Mr. Kruesi makes, *i. e.*, getting a perfect weld, has in our experience shown little effect. If the joint is made thoroughly, even if the weld is not perfect it is of great benefit, and if the weld is merely fairly good, it makes practically no difference. I want particularly to impress on the reader the fact that in almost all cases the welds are perfect.

NO. 1159

BALL BEARINGS

A DISCUSSION OF THEIR USE IN GENERAL AND ON AUTOMOBILES IN PARTICULAR

BY HENRY HESS, PHILADELPHIA, PA.
Member of the Society

The field of usefulness of the ball bearing is as wide as the domain of mechanical engineering, or at least that portion of it which is concerned with the support of rotating or oscillating parts.

2 The limitation imposed on the use of the ball bearing in no sense differs from that imposed on any other element of mechanism. It must be employed in accord with the general prohibition against overloading and in conformity with its individuality. That sounds axiomatic and is self evident enough; but self evident as it is, it is all too frequently disregarded.

3 But little reliable information on ball and rolling bearings can be found in the usual engineering hand and text books. Much matter is scattered through the technical press giving isolated experiences with a few bearings that happened to come within someone's observation. Insufficient information on almost every element that must be considered is undoubtedly responsible for the directly contradictory statements to be found and the generally accepted opinion that ball bearings are suitable only for relatively light loads.

4 This was the situation as Professor Stribeck found it, when asked to investigate the subject for the German Small Arms and Ammunition Factories of Berlin. This concern, having been induced to go into the manufacture of balls and ball bearings, very soon found itself confronted with the imperative need for a scientific basis, if the manufacture was to be removed from the domain of haphazard blind working, resulting sometimes in success and sometimes in failure, the one as much a result of pure chance as the other.

Presented at the Indianapolis, Ind., Meeting (May 1907) of The American Society of Mechanical Engineers and forming part of Volume 29 of the Transactions.

7. With [illegible] Professor [illegible] subject. [illegible]

CHAPTER I

[illegible]

1. The [illegible] of Professor [illegible] work.

2. [illegible] They may [illegible]

3. The [illegible] is the [illegible] of [illegible]. Lightly [illegible] bearing is [illegible].

4 A knowledge of the elastic qualities of the materials at the hardness under which they are used is imperative. It being the elastic behavior that is important with ball bearings as with all other engineering structures, tests of balls, such as are commonly made to determine ultimate rupture when pressed into a steel plate and using the depth of indentation of the plate or load at which rupture occurs, as a measure of ball quality, are not only of no value, but are misleading.

5 The quality of balls and of ball races must be determined from their behavior under loads in the neighborhood of the elastic limit. Balls may be subjected to loads increasing as the shape of the supporting surface more nearly becomes complemental to that of the ball. A ball running between races having a flat or straight line cross section will not support as great a load as though the section were that of a curvilinear groove. Such groove naturally must never have a curvature equaling that of the ball, since that would substitute sliding for rolling contact.

6 The frictional resistance of a ball bearing is lower, the less the number of balls. Usually bearings can be designed to have between 10 to 20 balls. For that, with

P_b = total load on a bearing consisting of one row of balls;
P_0 = greatest load on one ball;
z = number of balls;

$$P_0 = \frac{5}{z} P_b \qquad \text{(Stribeck's Equation 11)[1]}$$

The load carrying capacity of a ball is

$$P_0 = kd^2$$

in which

d = the ball diameter,
k = constant dependent upon the material and the shape of the ball supporting surface.

From Equation 11

$$P_b = P_0 \frac{z}{5}$$

substituting for P_0 from

$$P_0 = k\,d^2$$

gives

$$P_b = k\,d^2 \frac{z}{5}$$

[1] "Ball Bearing for Various Loads" by Professor Stribeck. A complete translation of this work made by Mr. Hess is published as an appendix to this paper.

7 As balls are usually made to English inches it is convenient to take the one-eighth of an inch as unity.

8 The following table gives *combination* values of k for different cross sections of ball race and for the materials used in the first ball bearings tried out and also for the improved steel alloys used later. These constants give P_b in kg.

9 If the cm. is preferred as the unit for the ball diameter, then the tabular values for k are to be multiplied by 10, or more accurately 9.92.

			
*SHAPE OF RACES →			$R = \frac{2}{3}d$
k for older materials..................	3 to 5.0	3 to 5.0	10
k for improved materials..............	5 to 7.5	5 to 7.5	15

* The shape of the races will be shown at the meeting.

10 *Speed of rotation, in so far as it is uniform,* does not affect carrying capacity. (This applies to radial bearings, but not to thrust bearings of the collar type; in these the carrying capacity decreases with increase of speed.)

11 But speed is rarely uniform; variations cut down the carrying capacity; sharp variations of small amplitude, particularly at high speed, have the more marked effect. Their reducing action is similar to the battering effect of sharp load variations.

12 *Load variations reduce carrying capacity,* the effect increasing with the amount of the load change and the rapidity of such change.

13 *Accumulated experience* with various classes of mechanisms is so far the only available guide for estimating the reductions in the constants k that must be made to take these influences into account.

14 The carrying capacity of a complete bearing is no greater than that of the weakest cross section that comes under the load. This applies to all those forms which have curved race sections of maximum sustaining capacity, except at a point where an opening is cut to permit the introduction of the balls; such bearings are, as to load carrying capacity, governed by the weaker cross-section at that point.

15 *The calculated carrying capacity can be realized only if all balls sustain their share of the load.* It is obvious enough that if a ball is smaller than those on either side of it, it will not carry its share of the load; should it be larger it will carry more than its share and may be overloaded. Uniformity of ball diameter is essential. The permissible variation in ball diameter will be governed by the deformation produced by a relatively small part of the total bearing load, so that the balance of the load may be distributed over the several balls.

Such permissible variations of ball diameters amounts to but little more than one ten-thousandth part of an inch.

16 *High finish of both ball and ball sustaining surfaces is essential.* The presence of grinding scratches will very materially cut down the cited values of the constant k. Of course this presupposes true surfaces underlying the high polish. It follows from this requirement that rust and acid must be carefully avoided as they are destructive of finish and truth of shape.

17 It may not be amiss to point out that *uniformity of quality of material, of hardness and of structure throughout are essential.* The mischief of using balls having different values of k is not simply confined to the individual ball; if for instance one ball were materially harder and so deformed less than its mates, it would take more load and might therefore overload the material of the race, which would yet be entirely suitable under a division of the bearing load among a larger number of balls.

18 *The frictional resistances of ball bearings* have, by actual measurement, been found to vary from 0.0011 to 0.0095. These are the coefficients of friction referred to the shaft diameter, thus permitting direct comparison with those of sliding friction. The higher values are due to conditions that cause a preponderance of sliding as compared with rolling friction. It must be remembered that there is no such thing as a bearing having only rolling friction; that might be possible were balls and races made originally with absolute truth of surfaces and were such truth then maintained by the absence of deformation under load. Ball bearings having a coefficient of friction materially above 0.0015 under the greatest allowable load are inadmissible because too shortlived. The high resistance indicates the presence of too large an element of sliding.

19 A good ball bearing will have a coefficient of friction, independent of the speed within wide limits, and approximating 0.015. This coefficient will rise to approximately 0.0030 under a reduction of the load to about one-tenth of the maximum.

20 Professor Stribeck's report is referred to for further details of his investigation.

Chapter 2. Materials

1 The prohibition against overloading demands recognition of the characteristics of the bearing materials.

2 Any material may be used that will not, under the working load, be so deformed as to prevent pure rolling. That means an absolutely inelastic material and one which unfortunately is, and more than probably will remain, undiscovered. But a slight narrowing is

admissible to make the demand read: *Any material may be used that will not, under the working load, deflect enough to prevent substantial rolling.* That recognizes that all materials deform under load. Such deformation means change of shape from the original truth and that in turn will cause some sliding combined with rolling; *this sliding must be held down to the irreducible minimum.*

3 Any material may be used that will not, under the working load, be stressed beyond its elastic limit; that is, a limitation which is possible of attainment.

4 The tooth of time would be worn out against such a bearing. Its design is entirely practicable for light work, but for the heavier loads, the requirement would lead to, usually, impractical dimensions.

5 Fortunately, ball bearings are satisfactory if they last as long as their associated mechanisms. The requirement may therefore be modified to read: *Any material may be used that will not, under the working load, be stressed sufficiently beyond the proportional limit, to bring about its destruction before the lapse of a desired working life.*

6 These conditions permit the use of practically all of the materials known to mechanical engineering. With very few exceptions, however, the load conditions are such as to demand steels of the highest grades and these most carefully tempered. For automobile use, with which this paper is primarily concerned, no others can be considered. That puts out of the running all merely case hardened materials. In these there is always a more or less sharply defined change of structure at some distance below the surface. Continued working will cause a loosening of the hard shell from the softer core, soon followed by a breaking up and very characteristic flaking of the surface. Usually this flaking is local; its action is increasingly progressive, soon involving the entire bearing.

7 What has been said of case hardened materials holds true also for those carbon steels in which the hardening is not carried substantially and equally through the entire mass.

8 An examination of the section of a broken ball showed a sharp structural change due to hardening at a fairly uniform depth of one-sixteenth inch below the surface. The ball had evidently been run under conditions which shifted the load over its entire surface; it was used in a running test and then broken to examine its structure. It so happened that the ball was caught just before it was ready to fail by flaking. The entire hardened surface had been loosened from the core in such way as to form an inner ball. Some relative movement of this shell and inner ball had undoubtedly taken place, as evidenced by the polished condition of the inner surfaces. This specimen was presented to me by Professor Stribeck, who retained the other half.

9 What is true and required of the ball materials is even more so for the races. With time the ball presents its entire surface to the load, the small vibrations and changes of load being sufficient frequently to bring in a new axis of rotation. Not so the race; that is fixed and so always exposes the same surface element to the load attack.

10 *The requirements of a good ball are:*

a Truth of shape and size. The permissible limit of error will vary with the character of the material. In general, the better the latter, that is to say the smaller its deformation under a given load, the more accurate must the ball be. It is evident that, were a ball so much larger than its fellows as not to deform sufficiently under its share of the load to permit the others to carry, it would then not only itself have to carry more than intended, but would also transmit more than intended to the supporting surfaces of the races. If, on the other hand, the ball were smaller than its mates, it would be underloaded or not loaded at all, and the others correspondingly overloaded. What has been said of variations in ball size, of course, applies similarly to variations from truth of outline.

All requirements will be met if the balls are true to shape within one ten-thousandth part of an inch and if all of the balls used in each individual bearing have a similarly small error in size. It must not be inferred that for materials of lower grade, larger inaccuracies are permissible. Were the load distribution the only factor, that conclusion might be justified; greater inaccuracy of size means greater deformation and therefore greater departure from sphericity and the substitution of too great a percentage of sliding for the rolling aimed at. Considerable initial variations from truth of shape have precisely similar results.

b Surface finish to a very high degree is also essential. What is usually considered a very good finish indeed may be characterized as totally inadequate. The recognition of grinding or polishing marks not only by the bare eye, but with an ordinary pocket reading lens condemns balls utterly; this is true of a bearing having long life under high loads and speeds. Oft repeated endurance runs under conditions where the finish was the only variable have abundantly proved this, at first unsuspected, fact. This was discovered while investigating an apparently inexplicable difference in lasting qualities. As life is too short for a try out under normal loads, overloads were resorted to; they demonstrated conclusively that the higher the finish, the better the endurance. The high finish must not be of the Brummagem or Reuleaux's "cheap but nasty" variety.

c The *elastic limit* should be as high as can be had. A limit of proportionality above the elastic limit is desirable.

d The *hardness and uniformity of hardness* throughout the mass of the ball to the highest attainable degree is essential.

e *Correct knowledge* and uniformity are more important than even these requirements of high elastic limit and hardness. It will not do to say that, though some balls of a lot may do better than others, the design may be based on the poorer ones. That would result in the better balls carrying more than their share of the load, much as and with the same bad effects described while considering truth of shape and size. Lower quality, provided it is uniform, can be allowed for. It will then merely affect dimensions.[1]

16 *Ball making machinery* has arrived at a very considerable state of perfection; but balls within a limit of one ten-thousandth of an inch of intended size are not yet being made without the sacrifice of other qualities. That is, however, not important beyond having some slight bearing on cost, since it is perfectly feasible to select and grade balls within the desired limit; but the hardware dealer's word for uniformity of size is not a safe guide; he is perfectly honest in throwing odd lots of $\frac{5}{8}$ inch balls into one box and in thinking the customer who objects because they vary a half-thousandth, or even two, a "finicky crank."

Chapter 3

CHARACTERISTICS OF VARIOUS BALL MAKES

An investigation was made into the qualities of various balls with a view to fixing on the best make to use. Balls were tested for the quality of their material by determining their behavior within the elastic and proportional limits. This was done by mounting three balls on top of one another and attaching extensometers to the top and bottom balls. As the readings corresponded to the total compression of two balls, the actual deformation at each contact point was one-fourth of this reading.

2 Not only were the deformations measured under loads varying from 50 kg. to 800 kg, for balls from $\frac{3}{8}$ in. to 1 in., but the permanent deformations also were determined. At least two consistent sets of tests were carried out with each ball diameter, using a new ball for each set.

3 *Hardness.* It is clear that, other things being equal, that ball is best whose permanent set is least with reference to the total deformation, i. e., the larger the ratio (permanent deformation $\div$ total

[1] Within limitations for reasons analogous to those referred to in 10a.

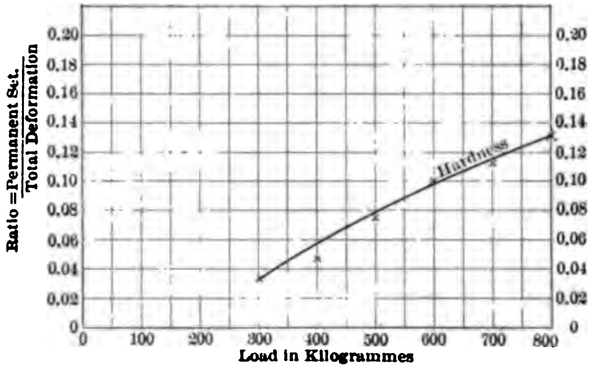


FIG. 1 BALL ¾ IN. × BALL HARDNESS

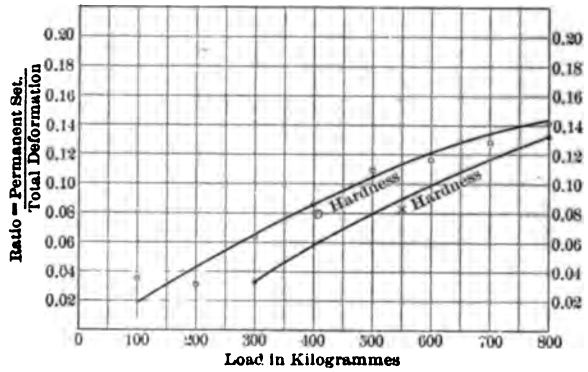


FIG. 2 BALL ¾ IN. × O BALL HARDNESS

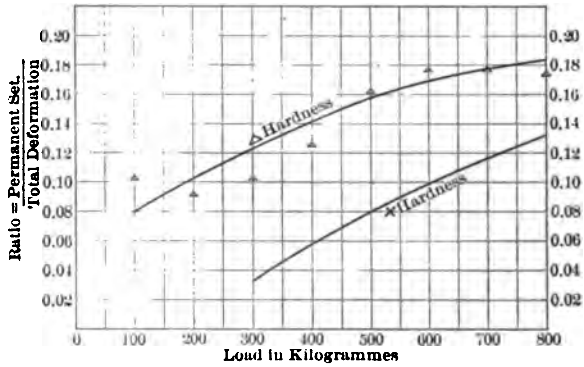


FIG. 3 BALL ¾ IN. × △ BALL HARDNESS

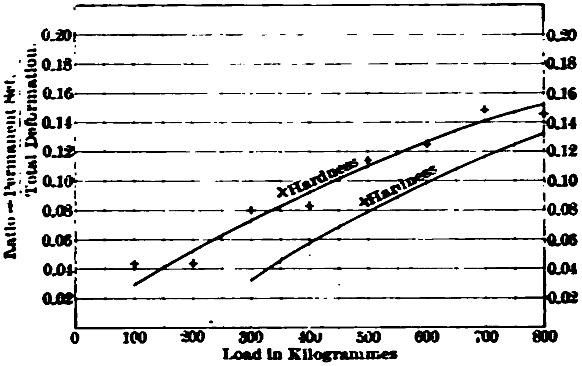


FIG. 4 BALL ¾ IN. × + BALL HARDNESS

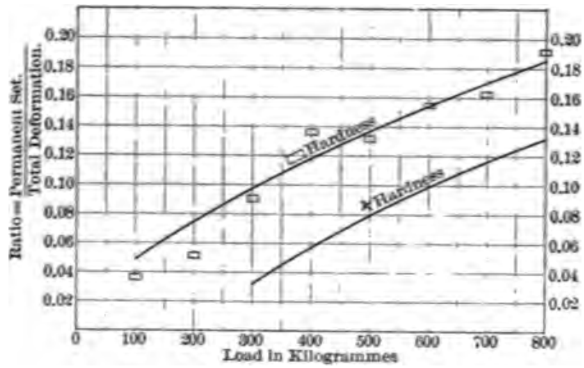


FIG. 5 BALL ¾ IN. × □ BALL HARDNESS

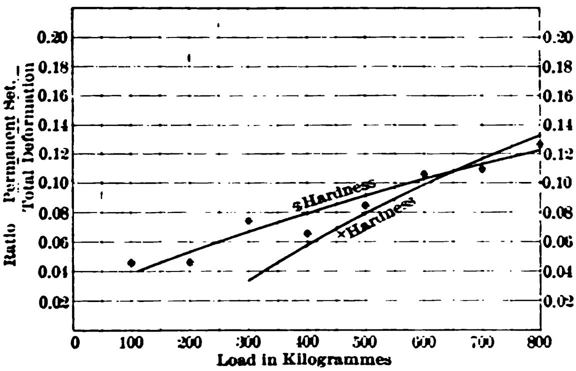


FIG. 6 BALL ¾ IN. × ⊖ BALL HARDNESS

FIG. 7 BALL $\frac{3}{4}$ IN. × O HARD O SOFT BALL HARDNESS
The two O balls came from the same lot, but varied greatly.

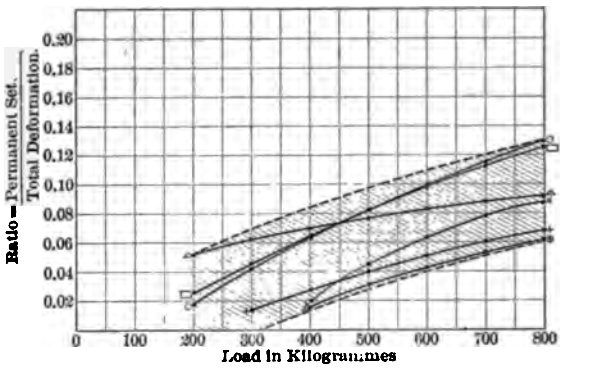


FIG. 8 BALL 1 IN. × O + △ □ ⊕ BALL HARDNESS RANGE

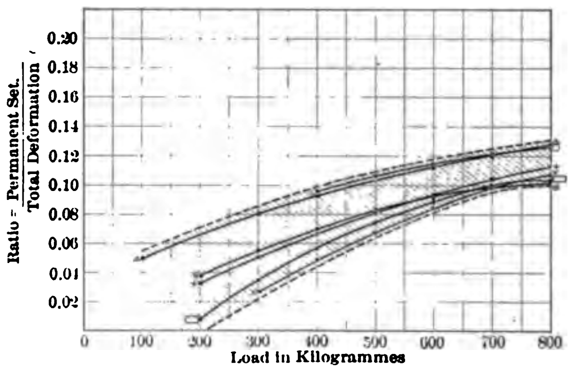


FIG. 9 BALL $\frac{7}{8}$ IN. × O + △ □ ⊕ BALL HARDNESS RANGE

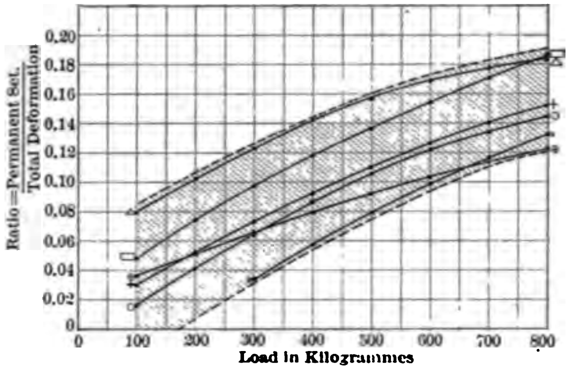


FIG. 10 BALL ¾ IN. × ○ + △ □ ⊕ BALL HARDNESS RANGE

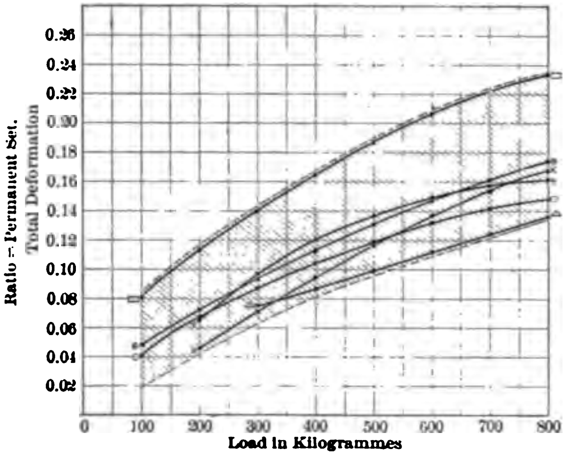


FIG. 11 BALL ⅝ IN. × ○ + △ □ ⊕ BALL HARDNESS RANGE

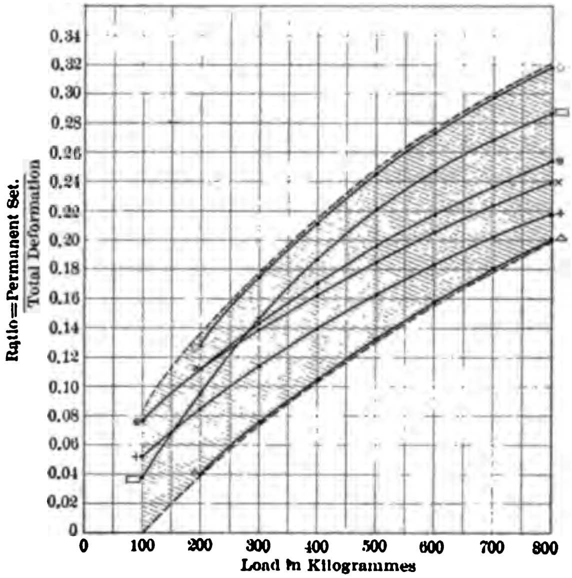


FIG. 12 BALL ½ IN. × ○ + △ □ ⊕ BALL HARDNESS RANGE

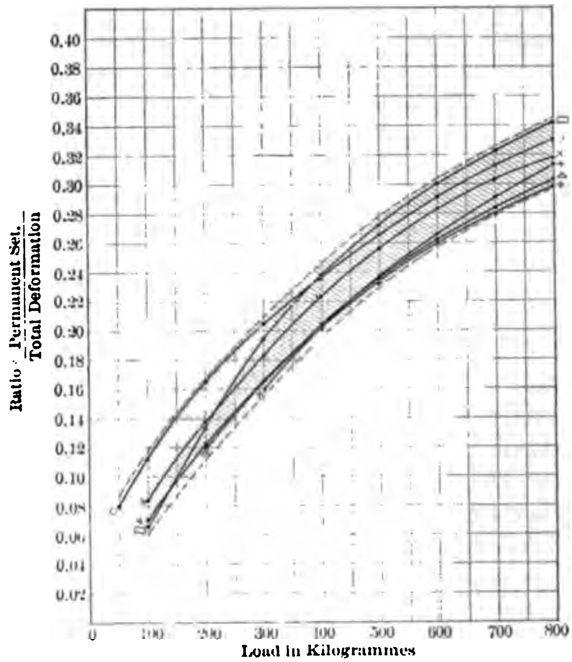


FIG. 13 BALL ⅜ IN. × ○ + △ □ ⊕ BALL HARDNESS RANGE

deformation) the better the ball. This ratio varies with the hardness and is therefore a convenient measure of the hardness. Six different makes of balls were tested: the deformations were most carefully determined at Cornell by Professor Diederichs, who was furnished with balls taken from a quantity bought in the open market. Of these balls three were of American origin, two of English, and one the present D. W. F. German ball. For obvious reasons the names are not given. but in the diagrams the balls are marked × ○ ÷ ⊥ ⊏ ⊖. The × is the D. W. F. Fig. 1 is a diagram in which the hardness of the × D. W. F. ¾ in. ball is plotted. The curve will be seen to fairly average the readings. The relatively small variations may be reasonably attributed to observation errors.

4 Fig. 2 gives the plottings and averaging curve of the ○ ¾ in. ball and also of the × for comparison. Fig. 3 to 6 are similar records of the ⊥ ÷ ⊏ and ⊖ ¾ in. balls. In all of these there is much greater difference between the plotted readings and the averaging curves; near the origin, where the deformations under the lighter loads are smaller, a larger part of the variations may, no doubt, be attributed to observation errors than further along under the higher loads; after making due allowance for this, it is clear that the relatively considerable variation in the hardness readings of all balls as compared with the small variation for the × ball is due to a lesser uniformity in the material, attributable to differences in chemical composition and heat treatment. Without taking up undue space by giving similar records of the various balls from ⅜ in. to 1 in. tested, it may be said that these all corroborated the testimony of the ¾ in. series shown.

5 Owing to the greater uniformity of the × ball and also because that uniformity indicates it as best for ball bearings with the manufacture of which the author is connected, the averaging line of this × ball has been drawn in for comparison in each diagram. Inspection shows that it lies generally below the others; the lower, the greater the relative difference in hardness in favor of the lower curve characteristic. Only in Fig. 6 does the ⊖ curve show up better than the × for loads of 700 and 800 kg., while less so for loads below 600 kg.

6 One particular make of ¾ in. ball, the ○, showed a most surprising variation in hardness. In Fig. 7 the lower curve is the × of Fig. 1, the second is the ○ of Fig. 2, and the upper is also a record of a ○ ¾ in. ball of the same make as the ○ ¾ in. of Fig. 2. This one upper ○ ball is rather more than four times as soft as the other (lower) ball.

7 The range of hardness variation of different sizes and makes of balls was found to be instructive. Fig. 8 shows this for the six makes of 1 in. balls. The range lies in the cross-hatched area bounded

by the upper and lower dash curves. For this diameter of ball, the variation is over 100 per cent at 800 kg. load and considerably greater under lighter loads.

8 As the ball diameters decrease, the relative variation in hardness of different makes becomes less, as is clearly enough apparent from an inspection of Fig. 8 to 13, inclusive. In Fig. 13, which relates to $\frac{3}{8}$ in. balls, the softest ball at 800 kg. load is only about 1.1 times as soft as against the more than two times of the 1 in. balls.

9 When these variations in quality are considered, it must cease to be a matter of surprise that such widely differing opinions as to the reliability of ball bearings are held. It may be remarked that the various balls tested all enjoy a good reputation. Makes of known poor grade were not tested, the advisability of adopting a different make of ball having been one of the objects of the investigation.

10 In the diagrams Fig. 8 to 13 inclusive, the characteristics of the various makes of balls have been drawn for a comparison of their relative hardness merits.

11 In considering these relations, the greater weight must be given the characteristics of those series in which the hardness range is lowest on the diagram, i. e., the showing of Fig. 9 for the $\frac{7}{8}$ in. balls is much more important than that of Fig. 13 for the $\frac{3}{8}$ in. balls. One location of a characteristic near the lower range limit of Fig. 13 is less important than such location in Fig. 9. Quantitatively this may be taken as follows: Over 800 kg., the lower range boundary of Fig. 13 is to the upper one as 0.296 to 0.342 or 1 to 1.16 (ratio of hardness scale at left). In Fig. 9 these figures and ratios are 0.100 to 0.130 or 1 to 1.30, which indicates that a similarly favorable location in Fig. 9 is about

$$\frac{1.30 - 1}{1.16 - 1} = \frac{0.30}{0.16} = 1.87 \text{ times as valuable as in Fig. 13.}$$

12 The relative hardness merit works out first $\times$, second $\oplus$, third $+$, with honors even for $\triangle$ and $\square$ and $\circ$ for the last place.

13 *Surface Character.* Micro-photographs were taken of the surface of the balls under a magnification of 35 diameters. The finish appeared to range all the way from fine scratches to pittings and even gashes. In the order of merit, balls $\square$ and $\times$ were found very decidedly above the others. Unfortunately $\square$ ranked third last in hardness, for which lack its good surface cannot compensate. Ball $\times$, second in surface finish, was also first in hardness.

14 *Grain Structure.* Opinions differ as to the validity of judgment based on the appearance of fracture surfaces. The leaning is on the whole toward a favorable consideration of balls that show the more uniform grain and more even fracture from the center to circumfer-

□ BALL

× BALL

○ BALL

FIG. 14 MICROPHOTOGRAPHS OF SURFACES OF BALLS, MAGNIFIED 35 DIAM.

ence, as well as the finer grain. Balls were split by compressive loading in a testing machine, holding three in line at a time. The balls are the same as those mentioned above. Micro-photographs[1] were made under an enlargement of 20 diameters, at the edge, about half way in and at the center of each ball. Those for the × ball show by far the more even fracture with very little choice as to the merit sequence of the balance. It is but fair to say, however, that Professor Rankin of Cornell, who made the various micro-photographs, considers that the × grain structure is coarser than the ⊕△ and + and much finer than that of the □ and ○ balls. In his opinion, for balls of the same general composition, the finer grain structure accompanies the greater resistance to breakage. Grain structure merit is △ +⊕ × □ ○ according to Professor Rankin, while to the author the photographs seem to indicate × ⊕ + △ □ ○.

15 *Microstructure.* Professor Rankin considers that no definite microstructures have been developed because the steels have not been held at a high temperature long enough, and that the originally definite crystal boundaries have been confused by imperfect annealing and slow cooling. Analysis shows a trace of graphite carbon in all but the × which shows rather more carbon in that state. There is generally a large proportion of martensite, with the balance made up of austenite and parts of cementite. The martensite is 92 per cent for the ○, 87 per cent for the +, 83 per cent for the ⊕, 82 per cent for the ×, 81 per cent for the △.

Chapter 4

VARIOUS TYPE CHARACTERISTICS

In the automobile, as in all other mechanisms, the journals deal with loads having various directions. In the order of their occurrence and importance they are:

Radial loads—acting at right angles to the shaft axis;

Thrust loads—acting parallel to the shaft axis;

Angular Loads—these may always be resolved into, or considered as made up of radial and thrust components.

RADIAL BEARINGS

2 Other things being equal, it is always best to arrange sustaining surfaces at right angles to the load direction. That gives the design of Fig. 14. Better carrying capacity is had from the modification in Fig. 15 in which races of curved cross-section are substituted for the straight line ones of Fig. 14. These grooved races have the advantage of greater

[1] Illustrations of these are omitted as the photographs are not adapted for reproduction.—EDITOR.

sustaining capacity, as referred to in detail elsewhere; as the tangent to the curve is normal to the direction of the radial load, the bearing is of the radial type.

3 As is shown elsewhere, the sustaining capacity of the bearing is dependent on the degree of curvature of the race cross-section, being greater as the latter more nearly approaches equality with the ball curvature.

4 Cutting a local groove from the side into a race for the purpose of assembling the balls between the two races is general (see Fig. 16),

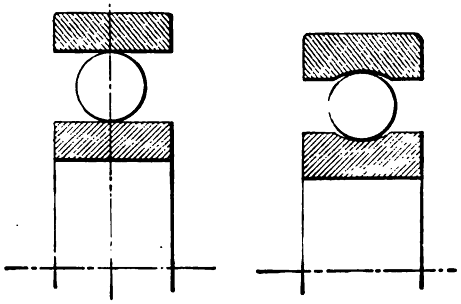


FIG. 15 RACES OF STRAIGHT AND CURVED SECTIONS

but is not good practice. If such cut is confined to one race which is then so held in the mounting as always to keep the opening at the unloaded side of the journal, this is at least defensible practice. The carrying capacity is then not decreased as the load is carried by cross sections of maximum sustaining ability. Unfortunately, this demands the use of two differing designs; the one with the cut in the outer race, the other with it placed in the inner race, according as the shaft or

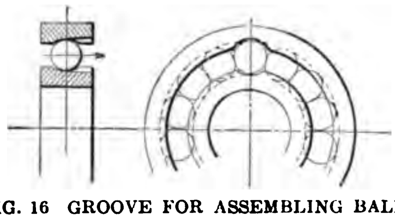


FIG. 16 GROOVE FOR ASSEMBLING BALLS

the housing rotates; the first case is the usual one of an ordinary journal; the second is found in wheel-hubs, etc. The occasional arrangement in which both hub and shaft rotate cannot be taken care of by this design.

5 It may be said here that high loads are dealt with. So long as the loads are low enough to be within the sustaining capacity of the straight line cross section, such local straight section at the filling

opening is of no moment. At high speeds this does not hold true, since the catching of the balls at the junction of the filling opening with the race, results in damage to the balls and, through these, to the race surfaces

6 With the cut in both races the carrying capacity is reduced to that of the straight line section at the side of the cut, since one or the other cut must come under the load in each revolution.

THRUST BEARINGS

7 The requirement that the sustaining surfaces should be at right angles to the direction of the load is responded to by the collar type of Fig. 8.

8 What has just been said of the cross sectional shape of the race surfaces in their relation to carrying capacity in radial bearings applies here also to the thrusts. Since the two races and the ball series do not form a unit handling as one piece, the need of a filling opening for the balls from the side does not arise. These bearings are frequently made with the surfaces A and B parallel. Provided such

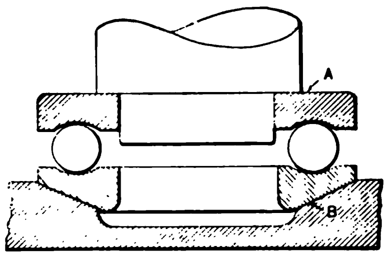


FIG. 17 THRUST BEARING

parallelism is secured, the design is good. Practically it is not realizable, since also similar parallelism between the collar of the shaft and the seat of the housing, though possible of initial attainment, cannot be maintained under the slight deflections due to the load. It must be borne in mind that initial errors in workmanship or deflections of a thousandth of an inch will cause the balls at one side to carry the entire load. For a given case this demands a bearing of needless size. By seating the one plate on a spherical surface, as B, this plate adjusts itself in such wise as to distribute the load over the entire number of balls.

9 Speed very decidedly enters into the carrying capacity of this type of bearing as a factor; so much so in fact as to greatly reduce its utility for speeds above 1500 revolutions per minute.

ANGULAR LOAD BEARINGS

10 Of these there are shapes and modifications innumerable. Fig. 18, 19, 20, and 21 may be taken as typical and representing two, three and four point contacts. In order to secure rolling, the contact points of balls and races should form points of a cone of rotation, whose apex lies in the center line of the shaft, or they may form points on the surface of an imaginary cylindrical roller that is parallel to the shaft. The defect in all of these forms is their adjustable feature. This places them absolutely at the mercy of every one capable of wielding a wrench; a bearing that has been properly proportioned with reference to a certain load, will be enormously overloaded by a little extra

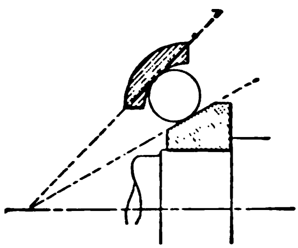


FIG. 18

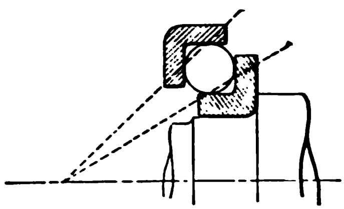


FIG. 19

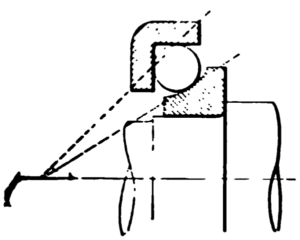


FIG. 20

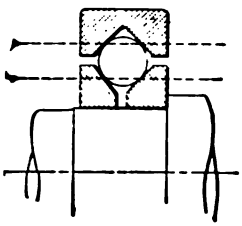


FIG. 21

BEARINGS SUPPORTING ANGULAR LOADS

effort applied to the wrench. Or the bearing may be adjusted with too much slack with consequent rattle and early demise. The prevalent idea that these bearings may be adjusted to compensate for wear is erroneous. Wear will form a groove on the loaded side of the race, deepest at the point of maximum load, about as in Fig. 22.

11 It is obvious that adjusting the cone endwise will only cause the balls to be more tightly pinched between the sound portions of the races, probably with sufficient pressure to overload; that will then cause an early flaking out, as shown at A in Fig. 23. These rough surfaces will quickly attack the balls and, progressively, the entire race.

The annular non-adjustable type of bearing will always, other things being equal, perforce have the important advantage of immunity from overload by maladjustment, no means for adjustment being provided.

12 Theoretically it would seem that the radial bearing would be incapable of carrying thrust load, owing to the wedging of the ball between the races. Fig. 24 shows the condition with the ball abso-

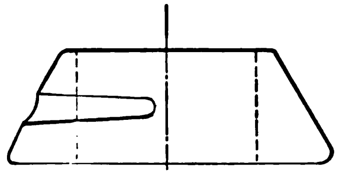


FIG. 22

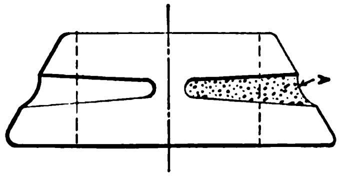


FIG. 23

WEAR OF ANGULAR RACES

lutely filling the space between the races. Fig. 25 shows the ball not quite filling this space. Fig. 26 shows the condition of Fig. 25 under the influence of a thrust load. The ball does not come in contact with the race grooves where these are deepest, but on one side, so that the tangent to the race curvature at the contact point forms an angle with the line of thrust. For Fig. 24 this angle would be infinitely small and the wedging action considerable. A calculation of the amount of the wedging action for Fig. 25 and 26 with the radial freedom

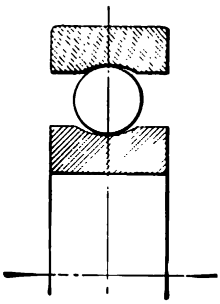


FIG. 24

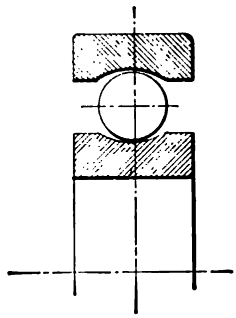
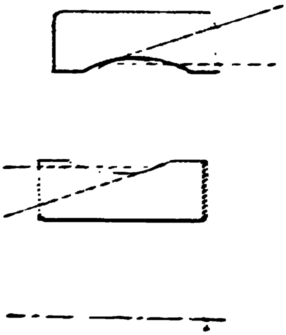


FIG. 25

CONDITIONS WITH THRUST LOAD

permissible in the bearings still indicates an inadvisably large amount of wedging. But actual running tests as well as a large fund of accumulated experience have absolutely proved that these bearings will carry much more thrust load than the calculation of the theoretical wedge angle indicates as possible. It is probable that the deformation which we know occurs at the point of ball contact and which results in small actual surface areas of contact instead of mere points, has a mean tangent to such compression surface of greater inclination, and that the wedge is therefore more blunt.

13. It has been experimentally determined that the thrust-carrying capacity of the uninterrupted type of an annular bearing is to the radial capacity as $\frac{1}{2}$ to $\frac{3}{4}$ to 1, depending upon the relation of ball



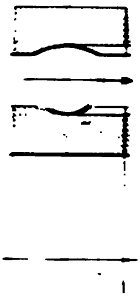
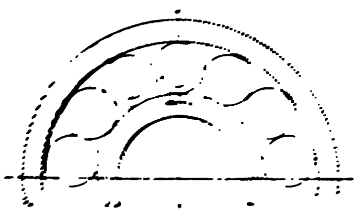


FIG. 26 FIG. 27

CONDITIONS WITH THRUST LOAD

diameter, race curvature, and number of balls. It has also been experimentally found and confirmed by experience that speed has very slight influence on this thrust carrying capacity; for speeds above 1500 revolutions per minute these radial bearings of the uninterrupted race type are more efficient thrust carriers than the collar type.

14. This is characteristic, however, only of the uninterrupted radial type. Those forms in which the balls are filled in through an opening in the side, Fig. 27, may manifestly not be subjected to end thrust, as that would cause the forcing of the balls into the interruption and their destructive pinching.



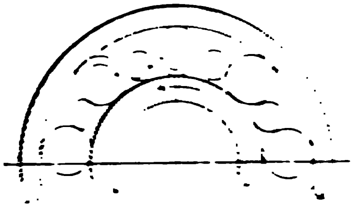


FIG. 28 FIG. 29

BEARINGS WITH AND WITHOUT SMALL SEPARATING BALLS

15. It is held by many designers of ball and roller bearings and others as well—that in such bearings adjacent balls or rollers are pressed against one another with considerable force. With the inner race of Fig. 28 rotating as indicated, the balls or rollers will also roll as indicated. The surfaces of the balls or rollers roll in opposite direc-

tions and therefore with sliding friction. This is assumed to be a serious defect by those who reason that these surfaces contact under pressure. The same general cure in forms innumerable has served to glut the records of our and various other patent offices. This cure, see Fig. 29, consists in the provision of smaller balls or rollers interposed between the larger ones, so that all contacting surfaces roll relatively to one another. The remedy is, however, fallacious in that it brings about the very condition it seeks to avoid. If two large balls,

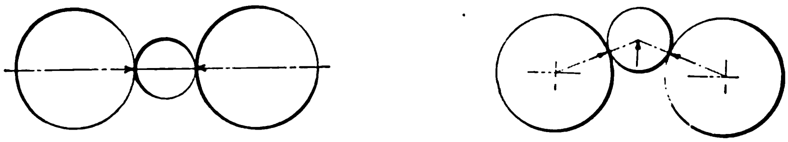


FIG. 30 FIG. 31
WEDGING ACTION OF SEPARATING BALL

(Fig. 30), compress a smaller one between them, and the three have their centers connected by a straight line, they will retain their relative positions. If, however, the interposed roller or ball, Fig. 31, has its center to one side, then this roller or ball will be forced outward. The resort to a cage for retaining the interposed roller or ball, results in the latter being pressed against the sides of the cage and in the forcible sliding contact that it was intended to avoid.

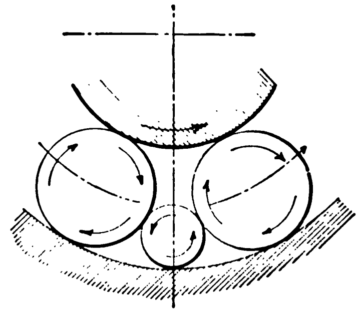


FIG. 32 SEPARATING BALL IN CONTACT WITH RACE

16 In another design, Fig. 32, the interposed member is brought into contact with the race. Following out the directions of rotation shows that the various rollers or balls are in rolling contact, but that the interposed member has the wrong direction with reference to the race against which it is forced.

17 These designs are all based on a failure to recognize an axiom in mechanics, according to which a force whose direction is normal to the supporting surface has no component in any other direction.

18 If a loaded plank, Fig. 33, is carried on two rollers, and plank and ground are parallel, the rollers will neither approach to nor recede from one another. If the plank is not parallel to the ground, but bent down between the rollers, Fig. 34, the rollers will be forced apart. If the plank were oppositely curved upward, the rollers would be forced toward one another.

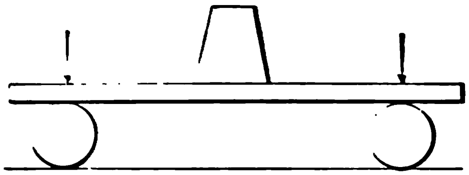


FIG. 33

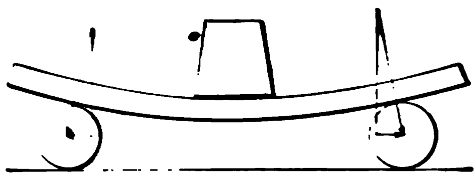


FIG. 34

DIAGRAMS SHOWING TENDENCY OF ADJACENT BALLS TO SEPARATE

19 As parallelism is concentricity with an infinite radius of curvature, the parallel plank and ground may be regarded as elements of a roller bearing of infinite diameter. A mere change in diameter, while retaining the concentricity of the two races, does not alter the conditions, from which it follows that the load carried by a ball or roller does not press the balls or rollers against one another.

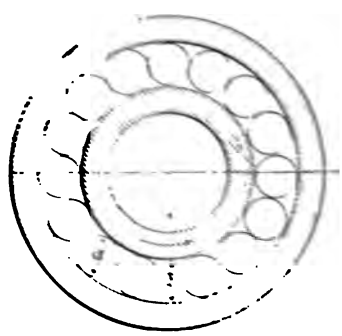


FIG. 35

ASSUMED WEDGING ACTION

20 This may be considered in another way. With the shaft of Fig. 35 loading the inner race the latter is (fallaciously) assumed to

act as a wedge, forcing the balls at the bottom apart and consequently producing pressure between the balls at the top. In that case the space δ must be rather smaller than a ball diameter d. The rotation of the inner race carries the balls around the bearing; the diameter a is therefore forced through the smaller space δ. To do this the ball must lift the inner race. The force to do this is imparted by the load, and is equal to the rolling friction and can therefore amount to but a fraction of that load. We would then have the absurd condition of this smaller force overcoming the larger original force. Were we to assume that the inner race is not raised by the ball in passing, but that the ball compresses sufficiently to get through, this would mean that the absurdity of the small force represented by the rolling friction was sufficient so to deform the ball or roller.

21 If a vertically loaded bearing which is not quite filled, as Fig. 36, be rotated slowly enough for observation it will be found that the balls are separated near the top and slightly forward of the vertical in the direction of rotation, and that the balls, under the influence of their weight, drop through this gap with a slight click; this click is familiar enough to those who have not yet entirely forgotten the days when their noses cultivated the intimate acquaintance of their bicycle handlebars. It is this click which is responsible for the high note of the high speed ballbearing of that type in which the races are filled with balls.

22 I may seem to have dwelt unnecessarily long on this fallacy of ball and roller bearing design; its surprising prevalence must be my excuse.

Chapter 5

CORRECT BALL BEARING MOUNTING

Ball bearings do not differ from other elements of mechanism, in that they must be used in conformity with their individual characteristics.

2 Some of the directions for correct mounting that are here cited must be absolutely adhered to under penalty of failure. These are given in a, b, c, d and e of Par. 3. To follow the others will be safe engineering; they are frequently disregarded, but such disregard is a standing invitation to trouble.

3 A strict adherence to all of the directions—and they are neither many nor troublesome—will result in a reliability as near to absolute as even the most exacting can expect—a reliability far beyond that of any other form of journal—and such reliability is gained with the

advantages of a practical absence of friction, small space occupied, and the minimum of attendance. Surely these are advantages enough to make a careful study and following of the directions worth while.

a The proper size selection for the load must be made. Rated capacities are usually for steady loads and speeds. Variations from these conditions demand recognition by a suitable cutting down of the listed capacity.

b Bearings must be lubricated. The oft repeated statement that ball bearings can be run without lubricant is pernicious.

c Bearings must be kept free of grit, moisture and acid. This prohibits the use of lubricants that contain or develop free acids. It is entirely practicable, by very simple means, to respond to *b* and *c*.

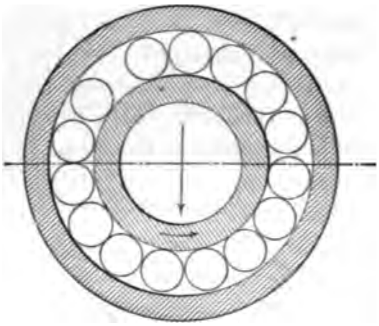


FIG. 36 CONDITION WITH VERTICALLY LOADED BEARING

d The inner race must be firmly secured to the shaft. It is best to do so by a light drive fit, re-enforced by binding between a substantial shoulder and a nut.

e The outer race must be a slip fit in its seat.

f Thrust ought always to be taken up, whether in one or opposite directions, by the same bearing. This avoids all strains due to flexure of the shaft or of the housing or due to temperature variation and, while doing away with the considerable shop costs inseparable from correct lengthwise dimensioning, avoids the danger of excessive end loads from forcible assembly consequent on an inaccurate lengthwise location of parts.

g Bearings should never be dismembered, or at least never more than one at a time; this will avoid the danger of mixing balls from different bearings; such balls from different bearings are apt to vary more than is permissible for the individual bearing.

ILLUSTRATIONS OF CORRECT MOUNTINGS

4 The ball bearing in its application to heavy work and serious engineering is of so recent a development that really very little information as to correct mounting arrangements for the various conditions that arise in practice is generally available. My experience has been that faulty mountings are so general that it is desirable to give elementary illustrations rather more in detail than would be considered necessary for a more familiar mechanical element.

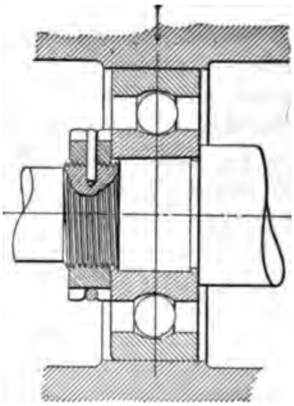


FIG. 37
RADIALLY LOADED ENDWISE FLOATING SHAFT

5 The inner race is a light driving fit on the shaft and is securely clamped between a shoulder on the shaft and a nut. As the edges of the bearing races are rounded, the shaft shoulder should be high enough to get a firm grip on the side surfaces; about half as high as the race thickness—rather less for larger bearings, rather more for small bearings—is good practice.

6 The outer race is a sucking fit in the housing so that the bearing as a whole can respond to relative shifting of the shaft and housing without being subjected to an uncontemplated end thrust through the balls.

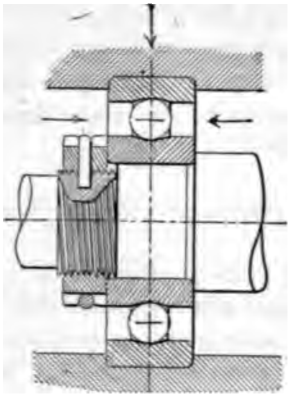


FIG. 38
RADIALLY LOADED SHAFT HELD AGAINST ENDWISE MOTION

7 Also for thrust load in either direction. Never more than one bearing should thus be held endwise as to its outer race. This differs from the preceding mounting only in having the outer race also secured between shoulders. Frequently, as in electric motors, some float of the shaft is wanted; a corresponding clearance between these outer shoulders and the race is then provided. This arrangement and the preceding one are usually found combined on the same shaft, which is then held endwise at one point only, so that temperature changes, or deflections of shaft or of bearing can cause no cramping. This mounting will take end-thrust also and in opposite directions. It is very frequently useful where it is desirable to take both thrust and radial load on one bearing.

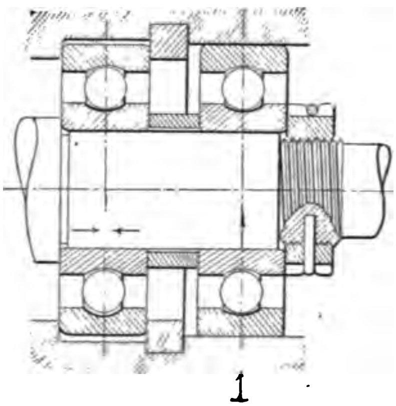


FIG. 39
SEPARATE RADIAL BEARINGS FOR RADIAL AND THRUST LOADS

8 It is occasionally desirable to take thrust load on bearings of the radial type, while the space available does not permit of a single radial bearing of sufficient diameter to take both loads. A second may then be so mounted that it is entirely free circumferentially and so cannot be loaded radially.

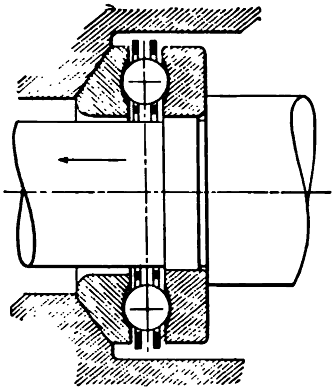


FIG. 40

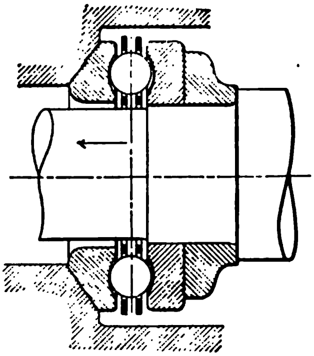


FIG. 41

THRUST LOAD IN ONE DIRECTION ON COLLAR BEARING

9 The stationary race is provided with a spherical seat so that it will distribute the load over the complete ball circle.

10 In order to permit compensating shifting, the fixed plate must be radially free of the shaft and of the housing. The shaft shoulder should reach high enough not to subject the rotating race to bending strains tending to dish it. Where it is inconvenient to provide a sufficient shoulder on the shaft, it is advisable to insert a suitable washer, as shown in the modification, Fig. 41.

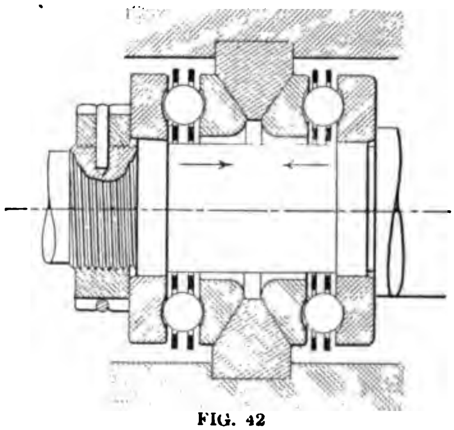


FIG. 42

THRUST LOAD IN TWO DIRECTIONS ON TWO COLLAR BEARINGS

11 This is simply a doubling of the preceding unit to provide for the reverse thrust.

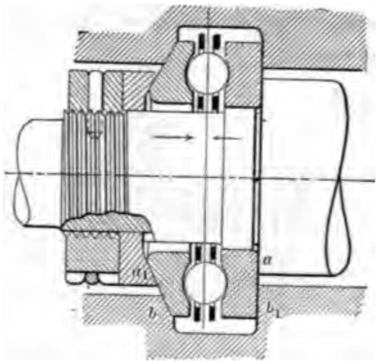


FIG. 43

THRUST LOAD IN TWO DIRECTIONS ON ONLY ONE COLLAR BEARING

12 This arrangement economizes in room, in cost of bearings and in number of parts.

13 While the shaft shoulder *a* and the housing abutment *b* are in intimate contact with the races due to the transmission of the thrust loads, the other abutment b_1 and the shaft nut a_1 are not under pressure and are slightly relieved by the spring of the parts, so that the lubricant can get between the surfaces. Reversal of the thrust will bring the erstwhile free shoulders into contact under load and clear the others.

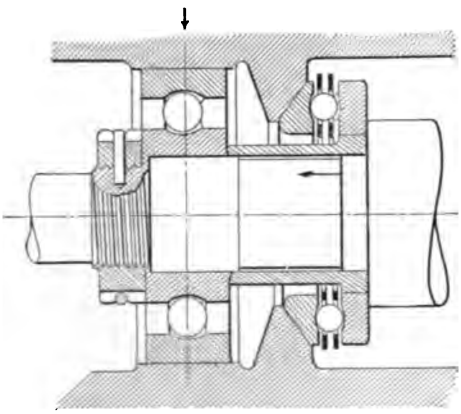


FIG. 44

RADIAL AND ONE DIRECTION THRUST ON COLLAR BEARING

14 This combination is an obvious one, not differing in principle of the mount from those already shown.

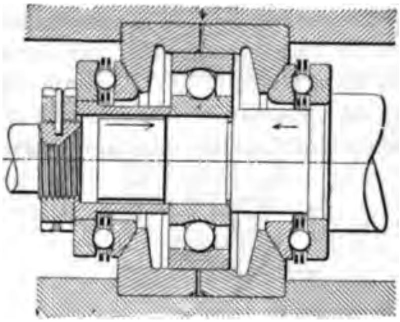


FIG. 45

RADIAL AND TWO DIRECTION THRUST ON TWO COLLAR BEARINGS; USED IN MOTOR BOAT AND YACHT PROPELLER SHAFTS

15 This is an obvious extension of the preceding arrangement in accord with the intended function. Attention may be drawn to the distance piece for transferring a binding thrust to the inner race of the radial bearing.

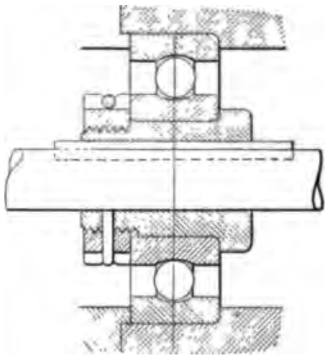


FIG. 46

SHAFT FLOATING THROUGH INNER RACE

16 It is occasionally inconvenient so to arrange an assemblage of parts that the inner races can be clamped to the shaft, or it is desirable to have a shaft slide through it. The peening effect of vibratory loads concentrated on so narrow a zone of the shaft as the race width would cause the cutting down of the shaft. Introducing a sleeve, on which the inner race of the bearing is firmly clamped endwise, gives a sufficiently long surface between sleeve and shaft.

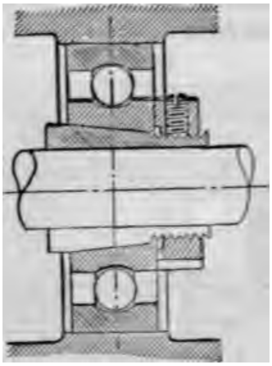


FIG. 47
ADAPTER BEARING FOR CONTINUOUS OR DRAWN SHAFTING

17 The bearing is tapered as to bore. Driving the split bush in will clamp both bearing and shaft and compensate for such size variations as are usually found in shafting. The nut must not be used to draw the bush in, but merely as a lock to hold it after it is driven home.

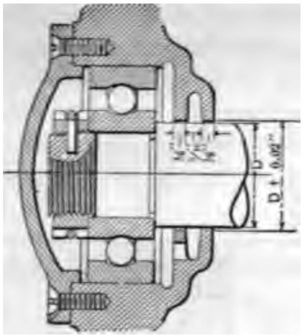


FIG. 48
BEARING CLOSURE—SINGLE GROOVE—NO PACKING

18 It is necessary so to enclose a ball bearing that the lubricant will not be lost by leakage and that foreign matter will be excluded. This shows one way that has been found efficient. Where a shaft terminates in a bearing, the outer end is best closed in completely by a suitable cover. Where the shaft passes out, a flange should be brought down to the shaft and bored out not over 0.02 inch in diameter larger than the shaft; this flange should be separated into two lips by an annular groove which may be either cored or bored, as may be

convenient. The lips should not be less than $\frac{1}{8}$ inch wide and should have sharp edges; rounding them over will defeat their object.

19 The groove should be provided with a hole or narrow slot at its lowest point to communicate with the bearing oil space. For a rotating frame—as a vehicle hub—several such drains should be distributed around the groove. The groove should have a width of not less than $\frac{3}{16}$ inch and a depth of about $\frac{5}{16}$ to $\frac{3}{8}$ inch. Filling the groove with a packing material will destroy its object just as soon as

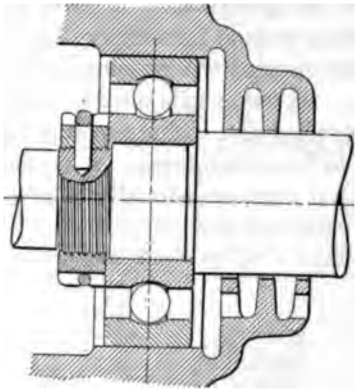


FIG. 49

BEARING CLOSURE—DOUBLE GROOVE—NO PACKING

the packing has worn sufficiently to hug the shaft no longer. This arrangement does away with the necessity of all spraying rings,

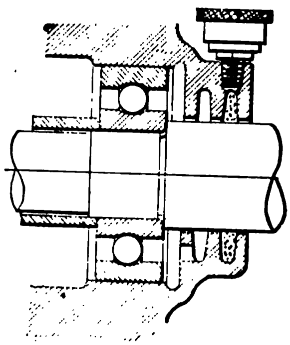


FIG. 50

BEARING CLOSURE—DOUBLE GROOVE—GREASE PACKING grooves, collars, pockets, and similar devices now much used. It fails of its object if there is radial wear.

20 This differs from the previous closure only in the provision of a second groove and third lip. The arrangement is employed where water is occasionally encountered and will prevent its entrance. What little may find its way past the outer lip into the outer groove is soon drained out of that again through the holes provided.

21 Where much impalpable grit is present, as in emery and other grinding machinery, a packing that actually hugs the shaft is necessary. Filling the outer groove with a fairly consistent grease will provide such a packing without introducing friction. A grease cup of the spring loaded piston type will automatically maintain the integrity of this packing. Its use entails some attention to the proper balance of grease consistency and spring pressure under the extremes of temperature likely to be encountered. A manually adjusted grease cup is less delicate, but must occasionally be given a turn.

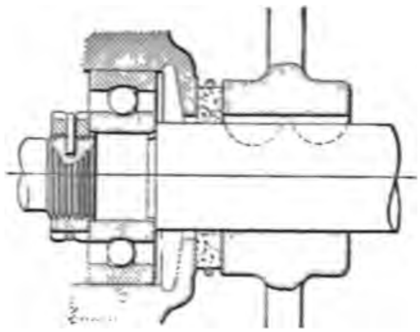


FIG. 51
BEARING CLOSURE—TAKE UP FELT RING

22 Some prefer a felt ring packing. They will find that to soak such ring in good soft paraffin and then to pass a split spring wire ring around it will force the outer edges of the washer outward to more intimate contact and cause the bore to hug the shaft, even as the ring wears. The action will be improved if the ring is not stamped out as a washer, but laid up from a strip with the ends scarfed; this will permit it to close up more freely under the constraint of the encircling spring.

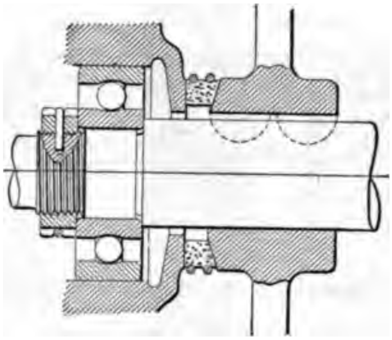


FIG. 52
BEARING CLOSURE—TAKE UP WEDGE FELT RING

23 Instead of having the felt ring hug the shaft it is tapered on one or both sides; the seal is then made entirely against the sides of the similarly shaped hub and boss.

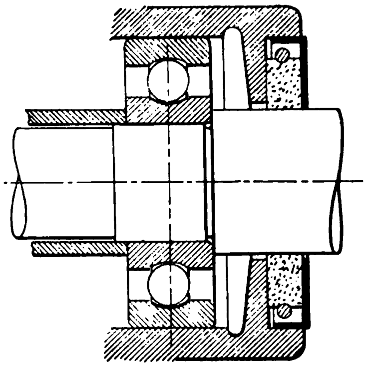


FIG. 53
A MODIFICATION

24 Whereas the two closures last shown were for insertion between the faces of a stationary boss and rotating hub, this modification is enclosed entirely within the one or other. The felt ring is set into a counter bore and held in place by a light metal cap that is sprung into place.

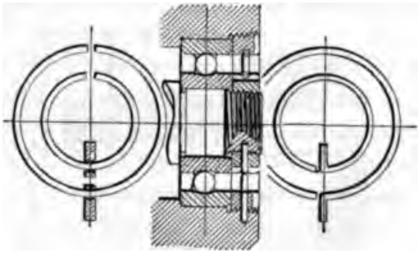


FIG. 54

A SIMPLE AND USEFUL NUTLOCK

25 Particularly with machinery that is subject to vibration it is necessary to lock firmly the nut that clamps the inner race. It is unsafe to rely on any form of a threaded lock; that also is likely to jar loose. Castellated nuts, etc., are unsightly and only permissible at the end of a shaft. The arrangement recommended consists of a split wire ring that is sprung into a groove turned circumferentially into the nut. A pin dropped into a hole drilled through the nut and partly into the shaft will be prevented from falling out by this guard ring. To permit of easily getting the pin out it is sometimes allowed to project and the ring is passed through a hole near the outer end of the pin. Not infrequently pin and ring are combined by bending the end of the ring over to act as the pin. The same arrangement is useful also when the nut is threaded on the outside to lock the outer race of a ball bearing, as shown.

CHAPTER 6

VARIOUS BALL BEARING MOUNTED AUTOMOBILE ELEMENTS TAKEN FROM CURRENT PRACTICE[1]

1 As it was the earliest, so the gasolene driven automobile is still the predominant type.

2 The illustrations are taken from working drawings courteously placed at my disposal by builders of that type of touring and commercial car.

[1] Blue prints of a large number of examples from actual practice were shown by the author under this heading at the time of the oral presentation of his paper. A few of these have been selected to be reproduced in this volume, to direct attention to the more important features brought out in the text.—EDITOR.

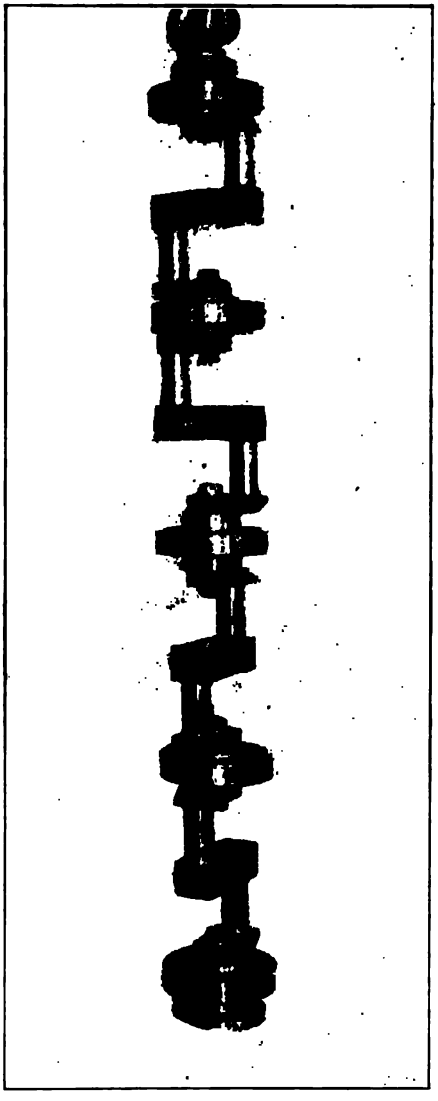


FIG. 55 SMITH & MABLEY CRANKSHAFT

3 Beginning with the engine, the crankshaft, camshaft and subsidiary shaft bearings, such as those of the fan and pump, come under consideration.

BUILT UP CRANKSHAFTS

4 A decidedly interesting crankshaft is made by Smith & Mabley. At 1200 revolutions per minute, the eight 7 inch diameter by 6½ inch stroke cylinders developed 190 horse power. The shaft is built up of similar units. Only the five main bearings are ball journaled. The shaft joints are placed directly under the inner races of the ball bearings. These joints are carried out as six jawed tooth clutches, the engaging faces of which are drawn together by body fitted bolts; the torsion effort is transmitted entirely through the jaws. The bolts, in conjunction with the shoulders on either side of the bearing seats, serve also to bind securely the inner races. Fig. 55 gives a fair idea of the appearance of the assembled shaft.

5 The same form of joint has been used in crankshafts by Noble, each unit consisting of one web and a half bearing seat; in his con-

FIG. 56 BALL BEARING CRANKSHAFT OF MOORE 40 H.P. CAR

struction not only the main journals, but also those for the connecting rods were carried out as ball bearings. Noble, however, used a body free bolt with a tapered head fitting into a corresponding seat and drawn home by a similarly tapered nut. I understand from Mr. Noble that this principle for building up crankshafts has been used also on standard English locomotives for plain bearings.

6 A well thought out built-up crankshaft is that of the Moore Automobile Company. See Fig. 56. In this, each unit consists of a wrist serving as a journal of the usual plain type for the connecting rod end; this wrist forms a single forging with a flange at either end; these flanges carry circular bosses whose center line corresponds with that of the shaft main axis. As the bosses extend into

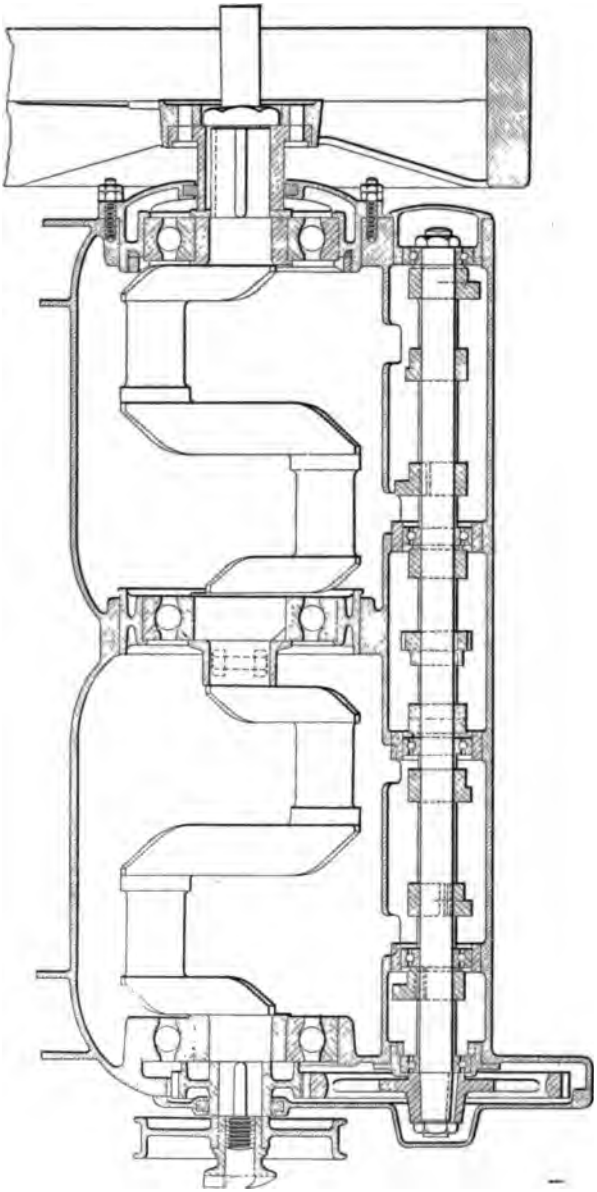


FIG. 57 CRANKSHAFT AND CAMSHAFT, F. B. STEARNS CO.

and fit the bore of the main journal ball bearings from both sides, six body bound bolts connect and align successive units while securely binding the inner races between the web flanges. Moore uses very large bearings, as compared with current practice, for his cylinder diameters and lightens his crankshaft by liberally boring out the wrists and main journal bosses.

ONE PIECE CRANKSHAFTS

7 Of one-piece crankshafts the Stearns, Fig. 57, represents good mounting practice. The bore of the bearing must be large enough to permit threading it over the webs. This is a four cylinder crankshaft with one central and two end bearings. The bore of the central ball bearing is large enough to pass over the webs to find its seat on the corresponding short wrist close up to one web. A narrow shoulder locates the bearing endwise. It is confined from the other side by a halved collar that fills the space to the other web; the halves of this collar are firmly bolted together. End crankshaft bearings are frequently selected of a smaller bore than the central ones as they need not be passed over webs; they must then be selected from a heavier series. In this case the designer preferred to use the same size bearings throughout. The difference in diameter of shaft and bore of end bearings was made up by bushes tightly fitted to the shaft and into the bearings. Structural simplicity and stiffness, with light weight of the crank casing, were secured by making this of one piece instead of capping it, as is the more general practice; the endwise assemblage that this demanded is responsible for the bushes that carry the outer races of the central and right hand end ball bearings. The bores for these bushes permit the insertion of the cranks.

8 This same drawing, Fig. 57, contributed by the Stearns Company also shows its practice in camshaft mounting on ball bearings. The shaft case is integral with that for the cranks and open only at the ends for assemblage. With the exception of the coned end for the driving gear, the shaft is of uniform diameter throughout its length. The cams, pinion, and inner races of the ball bearings, of which there are five, are all clamped endwise by end nuts by means of interposed tubular distance pieces. The bushings taking the outer races of the ball bearings are inserted merely to permit the endwise passage of the cams, the extreme radii of which are larger than the ball bearing semi-diameters.

9 To the employment of ball bearings for the main journals of gasolene engine crankshafts there is no known limit. In this Society's Transactions for 1906, was illustrated a crankshaft from

French practice, each main journal of which has to carry a working load of 20,000 pounds at 450 revolutions per minute. The acceptance run involved trying out under 28,000 pounds load per journal for 14 hours at 450 revolutions per minute.

10 The connecting rod end presents a more difficult problem. The velocity of the journal is continuously varying with the angular position. In larger engines the inertia of a ball that can withstand the rather violent effect of the charge opposes this continuous change of speed so as to cause a serious interference with correct rolling. In Europe, where this use of ball bearings is of sufficiently long standing, experience has shown that this influence is negligible for engines of less than six inches cylinder diameter.

CRANKSHAFT BEARING SELECTION

11 The load imposed on crankshaft bearings is governed by so many complex factors that it is more practicable to base the selection of a particular type of bearing on a simple rule of thumb, the substantial reliability of which has been proved by experience. For the conditions obtaining in gasolene engines of the automobile and marine type, an average pressure of 300 pounds per square inch of piston area is assumed, and a bearing selected whose rated carrying capacity for steady load and speed corresponds to the total so arrived at. For the main journals, provided these are equi-distant on either side of the cylinder center, bearings having five-eighths of this capacity will answer; for a different relative location larger bearings, corresponding each to its location lever arm, must be selected. Such bearings have invariably proved sufficient for any size of engine for the main journals and on the connecting rods for cylinders up to six inches diameter, while often, too, bearings of three-fourths of this capacity have been found satisfactory. Experience has proved that motors of similar cylinder dimensions impose widely differing loads on their journals.

12 The automobile industry, possibly more than any other, shows clearly the universality of modern engineering and the obliteration of engineering lines. Many of the features found in the mechanism of both foreign and American machines are the result of experience, which has led to certain established principles of design incorporated alike in machines of foreign and domestic manufacture. A decidedly good design as to mounting is found in Fig. 58, a change gear contributed by the Locomobile Company of America. Every inner race is securely bound endwise between substantial shoulders and locked nuts or interposed distance pieces. Every shaft that is held

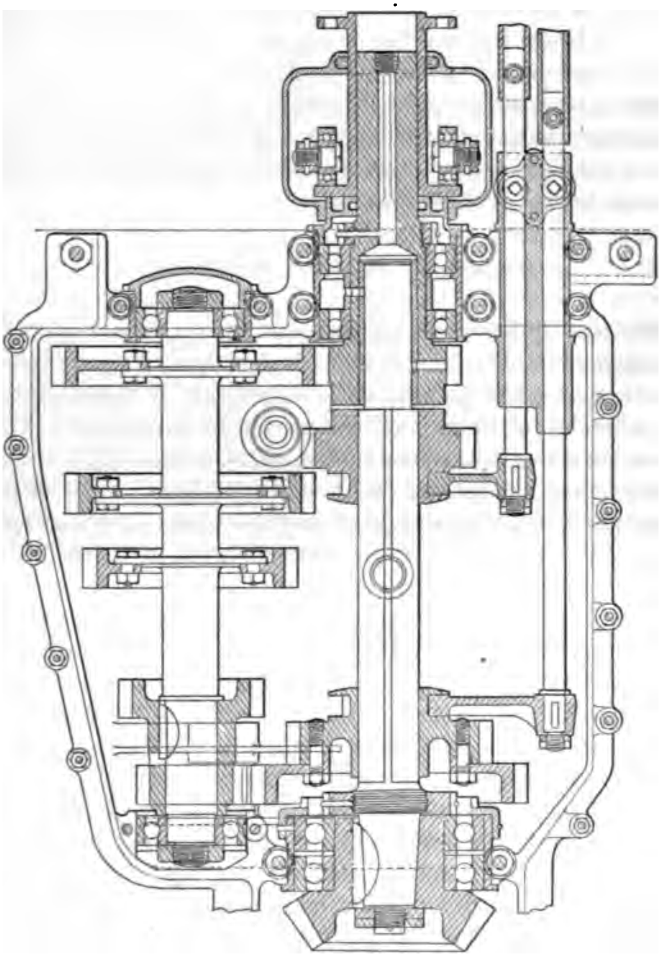


FIG. 58 TRANSMISSION CASE OF THE LOCOMOBILE COMPANY

against lengthwise shifting is so held in both directions at one bearing only. The possibility of imposing uncontemplated end-thrusts on any bearing by setting up any nut too far is guarded against, since the design will not permit any such maladjustment, either because the nuts come up solid or are provided with one-position locks. The end-thrust of the bevel gearing is taken on the rear member of each pair of radial bearings, its housing seat being sufficiently cleared radially to insure that.

13 The Pierce "Great Arrow" change gear of Fig. 59, shows that the dictates of experience for reliable ball bearing use have been care-

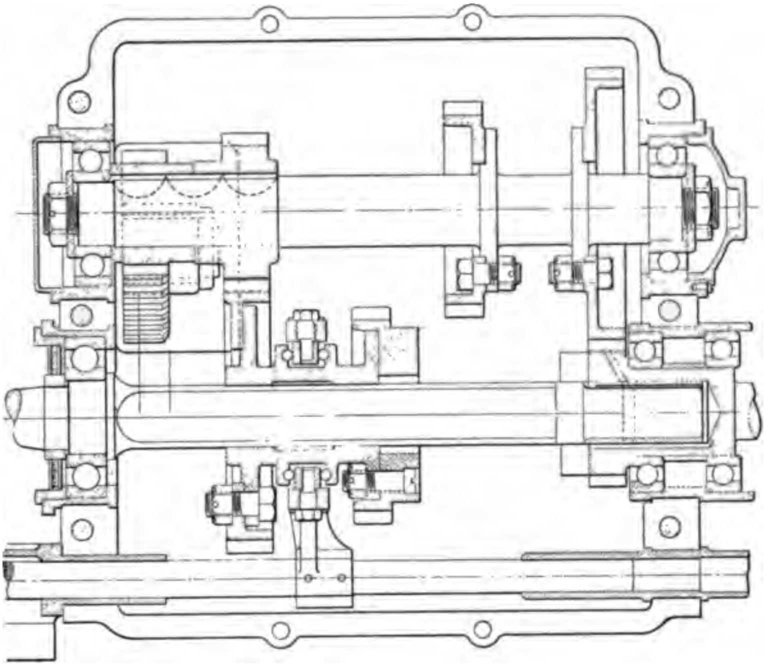


FIG. 59 TRANSMISSION CASE, THE GEORGE N. PIERCE CO.

fully incorporated. All inner races are driven on their seats and also clamped between shoulders and nuts. All outer races are slip fits in their seats and are free endwise except where the ball bearings are to secure a shaft or spool lengthwise. This office is always assigned to only one bearing on a shaft, so that no deflections of either housing or shaft, or variations in length due to temperature changes, can bring about unpremeditated end-thrusts; as this arrangement at the same time allows considerable latitude in the lengthwise relationship of shoulders on shaft and housing, shop economy as well is promoted.

14 In certain makes the various ball bearings for the change gears are not mounted directly in an aluminum case, but are in interposed bronze sleeves. This is a practice surviving from the earlier days when the aluminum castings were rather too soft to permit concentration of general loads on narrow areas corresponding to the ball bearing races. Many builders, however, now find it quite safe to dispense with these bushings even where crank shafts give a rather severe hammering load.

TRUCK GEAR CASE

15 That ball bearings are equal to the conditions of the heavier commercial vehicles as well as to those of the touring car type heretofore shown may be left to the evidence of Fig. 60, a gear case used by Mack Brothers in the chassis on which they mount not only their sightseeing bodies, but also those for their 2 to 10 ton trucks. Bearings of the radial type are used throughout and carry the radial loads as well as the thrusts of the bevel gearing. Since 1905 there have gone into use some 63 of these cars. That a close grained cast iron makes a very satisfactory liner is shown by this case, in which that material is interposed between the ball bearings and the aluminum housing. Convenience of access from underneath is provided by holding the liners up by encircling stirrups, so that the entire case cover can be dropped. The whole design commends itself favorably to the writer as in line with his preference, as an old machine tool designer, for always substituting a separate tooth clutch engagement for sliding gears. The universally favorable experience with clash gears is only another instance of the upsetting of traditions and supposedly inviolable rules of experience. What sane designer outside of the automobile field would, for instance, submit his gears to such stresses and speeds as are standard in automobiles and under most adverse conditions? Yet such gears work, work well and certainly last well also.

CHANGE GEAR BEARING SIZE SELECTION

16 The conditions under which the ball bearings have to work in change gears are so varied that it is practically impossible to give universally adequate directions for a proper selection of sizes. The location of the case on the chassis, whether near the motor or close to the rear axle, the mode of suspension and other elements which will greatly affect the severity of the road hammer, the relative use of the various speeds as determined by the character of the country, as well

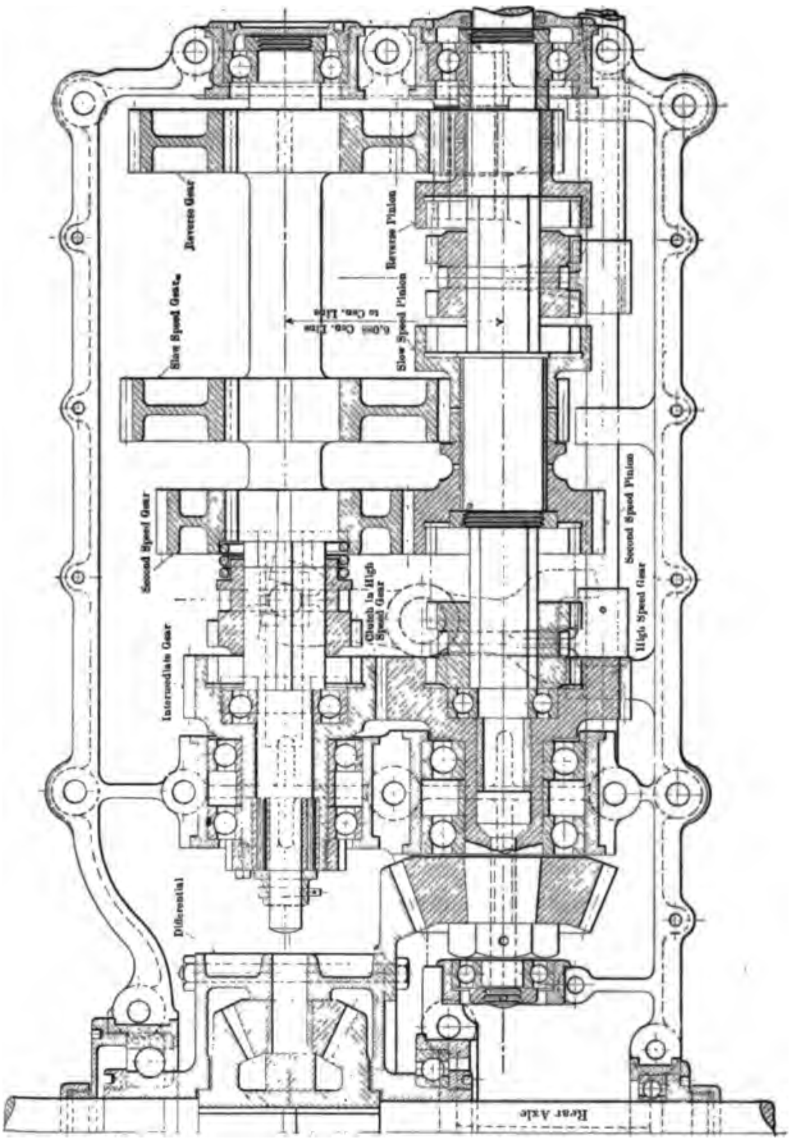


FIG. 60 MACK BROS. TRANSMISSION CASE

as that of the drivers, even the uncertainty as to the power actually transmitted, all are factors which should be, but which cannot be, taken into quantitative consideration. The best guide must be the experience gained by the bearing manufacturer in carefully following up the performance of various cars. While he can place that experience at the disposal of interested inquirers in the shape of definite suggestions based on data submitted, the inquirer himself generally prefers to make out at least a first design. It may be safely said that, as a rule, bearings of the medium series will answer for gear cases where such hearings are to be mounted directly on the shafts; it is the shaft diameters that will then usually compel sufficient size.

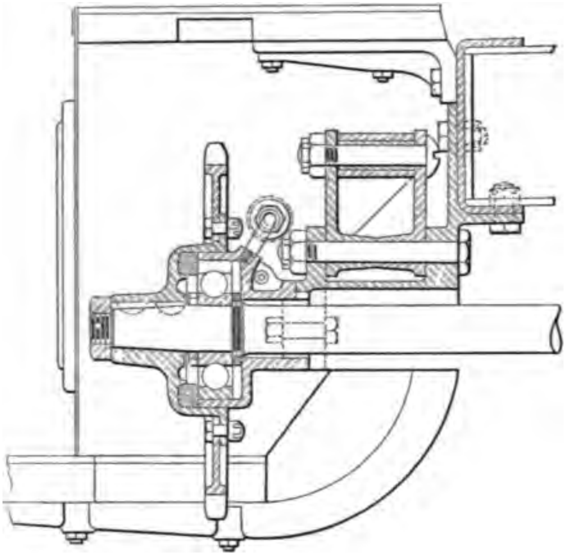


FIG. 61 JACKSHAFT AND SPROCKET OF THE LOCOMOBILE COMPANY

17 Where bearings are mounted on a spool or hub through which a shaft passes, the greater size consequent on the larger bore will usually make a selection from the light weight series practicable. Exceptions are frequently encountered where the bearings are to take the end thrust of bevel gears, as for instance those mounted on the sleeves of the differential gears; here usually a light weight bearing will answer for the non-thrust side and one of corresponding bore from the medium weight series for the thrust side to take combined thrust and radial load. If thrust and radial loads are taken on two separate radial bearings these may be often both taken from the light weight list. Where bearings of the collar type are preferred to take the

bevel gear thrust, it will generally do to select a bearing whose bore will correspond to the contemplated location. Bearings of the heavy weight series are but rarely required; their use is generally due to a desire on the part of the builder for great excess in load capacity.

SPROCKET BEARINGS AND SIZE SELECTION

18 A single example of good design in sprocket mounting taken from the practice of the Locomobile Company and shown in Fig. 61 will do. The principles of mounting are not different from those laid down for other elements. To mount the bearings as nearly in line with the chain-pull as possible is always advisable. A safe guide to

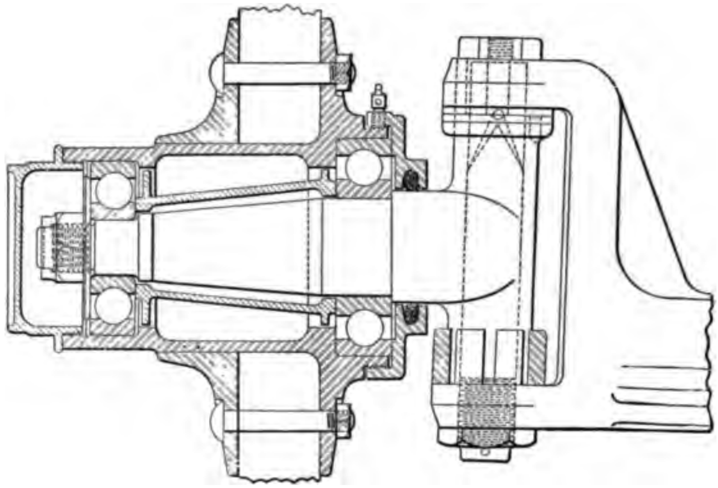


FIG. 62 FRONT HUB, THE LOCOMOBILE COMPANY

size selection will usually be found in the demands of the shaft as to bore and response to the extra stresses of loose and slapping chains by making the selection from the heavy weight series.

REAR AND FRONT WHEEL DESIGNS

19 A design that is very good is reproduced in Fig. 62 from the practice of the Locomobile Company. The inner races of the bearing are driven on and clamped by the use of the single castellated end nut; an interposed tubular distance piece bridges the gap from the outside to the inside bearings and so serves to bind both races. Flesang at either end of this distance piece extend both inward and outward to the axle and the hub; these are an ultra con-

servative designer's safeguards for supporting a wheel should the bearings fail. A large washer bridging the annular space between the inner and outer race of the front bearings will keep out much of the grit, etc., that would otherwise get into the bearings should the hub cap be knocked off when trying conclusions with some passing wheel. All thrust in either direction is taken on the inner bearing which is, as to its outer race also, firmly clamped endwise; the outer race of the other bearing is free and therefore subject to no end-thrust.

20 The influence of the relative location of the bearings and the center of the wheel tread on the size of the bearings is clear from a comparison of Fig. 62 already described and this Fig. 63 of the "Great

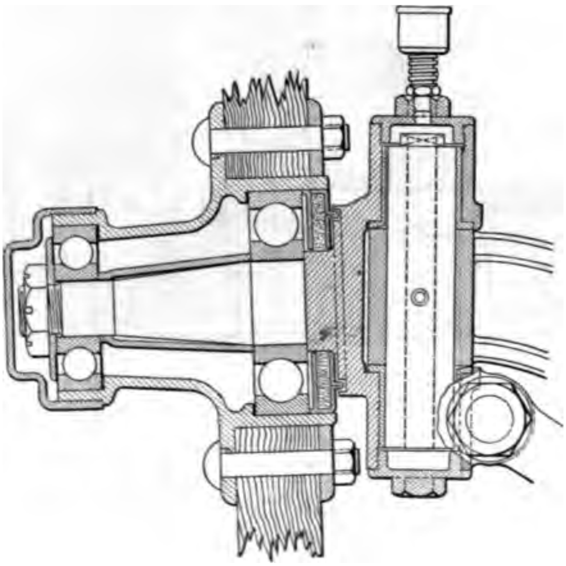


FIG. 63 FRONT HUB OF GEORGE N. PIERCE CO.

Arrow" front hub. In this latter a location of the tread more directly in line with the inner bearing throws more of the load on that and so compels the employment of a relatively larger bearing for this place. The necessary difference is, however, not quite that shown, part being due to personal preferences. Both are ample as to size.

21 A direct axle driven rear hub is that of Fig. 64, again from the "Great Arrow," which throws the entire wheel load on to a single liberal ball bearing that also takes all wheel thrusts.

22 A favorite German heavy truck front hub and steering pivot is that of Fig. 65 taken from a truck of 10 tons dead weight to carry a load of 5 tons. One of these has demonstrated its qualities in the decidedly

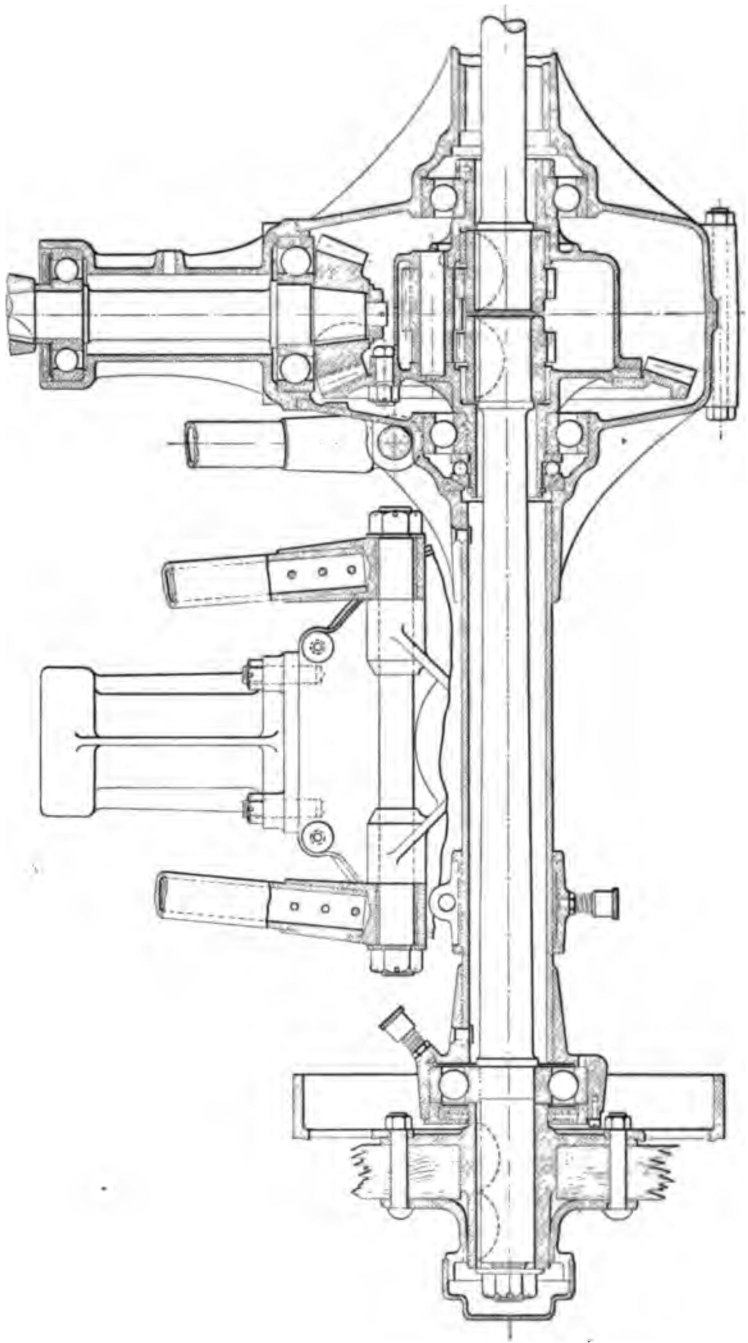


FIG. 64 REAR AXLE, GEORGE N. PIERCE CO.

heavy work incident to a shop removal from Berlin to the suburbs in the transfer of much heavy machinery under hurry up conditions. If proof of the preëminent advantage of the modern motor truck were needed, this work conclusively demonstrated it, in active and forced day and night competition with horsedrawn vehicles.

23 While the power loss due to friction at the steering pivot can never be serious, since, though with plain steps the friction is high, the speed and distance are slow, nevertheless the substitution of a ball step greatly facilitates the ease of handling and provides that responsiveness of the steering wheel that the man at the helm values highly and that gives him the impression that his vehicle is a sentient being, rather than a mere inert piece of mechanism.

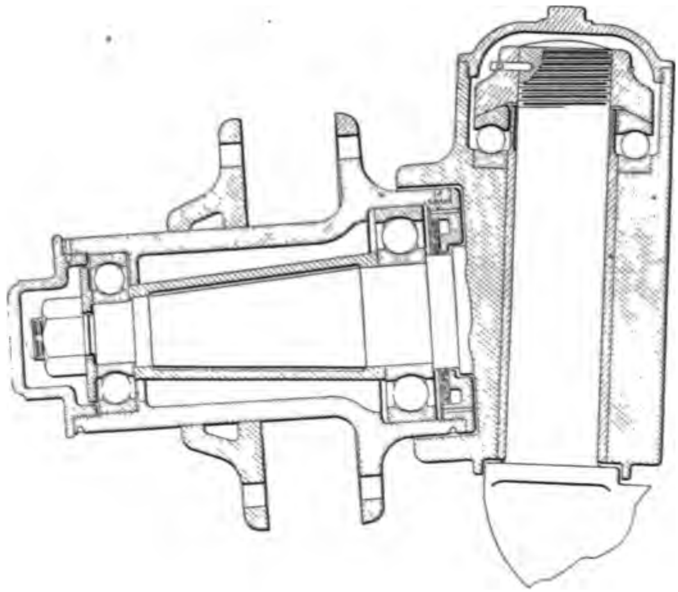


FIG. 65 STEERING HUB, GERMAN TRUCK. 5 TONS DEAD WEIGHT TO CARRY 5 TONS LOAD

BEVEL DRIVEN REAR AXLES

24 A typical arrangement is that of Fig. 64 taken from the Pierce "Great Arrow." Both radial and thrust load due to the bevel pinion are taken on the same radial bearing, but when it comes to the bevel gear, the designer prefers to take these separate loads on separate bearings. A collar type of ball bearing is therefore placed behind the radial bearing on the thrust side of the differential hub. The spherical compensating seat for the stationary ball plate permits the employment of a

more convenient, smaller bearing than was general in older practice using flat, non-compensating races.

25 An example of a rear axle of the floating type is the Nordyke and Marmon axle, in which the wheel bearing is relieved of all thrust loads. These are transferred to and through the axle so that the inward thrust is taken up on the collar ball thrusts on the opposite side of the differential, while the outward thrust is taken up on the collar ball thrust on the same side of the differential.

26 Notwithstanding that the radial form of annular bearing of the uninterrupted (D. W. F. or H. B.) race cross section is taking wheel thrusts in many cars besides those illustrated, there are still many designers who hesitate to be convinced. The construction last described meets their fears by transferring all thrusts to the central, collar type, ball bearings.

HUB AND AXLE BEARING SELECTION

27 The remarks about bearing selection made in connection with change gears apply with equal force to those for rear axle bevel drives.

28 For front and rear hubs, where these are supported on two bearings, it will usually be safe to consider one third of the entire load of a car plus passengers at 150 pounds each as coming on one wheel; about 10 per cent of this taken off for a front wheel and 10 per cent added for a rear wheel will sufficiently allow for the greater rear loading.

29 A bearing pair should be selected whose combined steady load and speed rating should be not less than one half greater than this figure, provided that the center of the wheel tread is placed about twice as far from the center of the outer bearing as from that of the inner one and provided further that the rated capacity of the outer bearing be not less than two-thirds that of the inner. Either bearing may be arranged to take the thrusts, but it is always preferable to take both thrusts on the same one. Shifting the tread center will demand a larger bearing for the one toward which the shift is made; for the extreme location directly in line with the bearing center, the rated capacity of that one should equal the full one and one-half wheel loads, as determined above.

30 The thrusts had then best be taken on the outer bearings. Where a single bearing carries the entire wheel load, the size selection will be the same as governs when the tread is located in line with the inner bearing. Also, as a rule, bearings of the light weight series should not be employed in wheels even though their rated capacity is sufficient; the road shocks call for larger balls than are usually

found in the light weight bearings, unless such of quite abnormal bore should be chosen.

31 It is understood that this is but a rule of thumb, in which no constants for the varying influences of diameter of wheel, length of wheel base, radius of turning curves, speed, etc., are recognizable. The assigning of proper values to these elements is not possible, or rather not as yet.

32 On the other hand, experience on all sorts and conditions of roads and road apologies in the United States and Europe has proved that these directions give as good a selection as can be tentatively made. It should naturally always be carefully scanned in its applicability to each individual case in the light of analogous experience. It is to be borne in mind that these general directions for hub bearings apply to pneumatic tires, and that for solid rubber, wood, steel, etc., the selections should be raised one-third.

Chapter 7

CONCLUSION

Although the idea of substituting rolling for sliding friction is nearly as old as mankind itself, dating from the time when man, condemned to labor, applied his observations of the relative ease of rolling an approximately round stone down on his enemy as against sliding a flatter one, to an easing of that labor, it is only within a few years that material progress has been made.

2 In the preceding pages the matter was dealt with from the standpoint of the usefulness of the ball bearing to the self-propelled vehicle; this necessarily limited the discussion to just enough of general matter to make intelligible and reasonable the various directions and selections for type selection, size determinations, and mounting arrangements, culminating in examples from standard practice of various firms that courteously placed their drawings at the author's disposal.

3 The time and space available in the Society Meetings and Transactions and the good nature of an engineering audience further restricted the scope. As much has been omitted that some might wish to have considered, these conditions must serve in extenuation. A great deal of matter on the behavior of ball bearings of many different types under various conditions has been accumulated and is still being added to. Much work in the trying out of various materials, on the influence of their chemical and physical characteristics, on the influence of heat treatment, on methods and apparatus for testing, has been

done, is being done, and still remains to be done. The author will take much pleasure, as occasion may serve, to make such contributions along these lines as may appear of general interest and will take particular pleasure in answering now or later any demands for information on any phase of interest.

APPENDIX

BALL BEARINGS FOR VARIOUS LOADS

REPORTS FROM THE CENTRAL LABORATORY FOR SCIENTIFIC TECHNICAL INVESTIGATION

BY PROFESSOR STRIBECK, NEUBABELSBERG NEAR BERLIN

TRANSLATION FROM THE GERMAN, BY HENRY HESS, PHILADELPHIA, PA.
MEMBER OF THE SOCIETY

About two years ago[1] the Central Laboratory had occasion to take up the design of ball bearings for the heavier loads, in the interest of the German Small Arms and Ammunition Factories of Berlin, (Deutsche Waffen- und Munitionsfabriken). At that time there were not available sufficient data on either the permissible loading of balls, nor yet on the frictional values of ball bearings. Consequently the first task was the experimental determination of such design data.

2 The more important results of this work have in the meantime been confirmed by experience in practical work.

3 Since these results are applicable not only to ball bearings, but also to a much wider technical domain concerned with the contact of elastic bodies, a detailed report appears advisable.

OCCURRENCES AT THE PLACES OF PRESSURE

4 The inquiry into the permissible loading of balls includes many problems. From the consideration that the occurrences at the places of pressure are essential to the behavior of balls and races, the first problem is to determine these in their dependence upon the load.

5 Hertz, in his work "On the Contact of Elastic Bodies" (Ueber die Berührung elastischer Körper), examined the general case of two elastic bodies of any shape when pressed together. The admissibility of his deductions is dependent upon the following assumptions:

[1] This report was written in 1900.

Presented at the Indianapolis, Ind., Meeting (May 1907) of The American Society of Mechanical Engineers and forming part of Volume 29 of the Transactions.

a The bodies may be in contact only at small parts of their surfaces.

b There must be no forces except such as act normally upon the surfaces in contact. This would be the case, as stated by Hertz, if the surfaces in contact were perfectly smooth.

c The materials must have proportional limits, and at the same time the deformations corresponding to the proportional limits must not be exceeded.

d The bodies must be homogeneous.

6 For the case of the balls, chiefly considered in this work, having radii r_1 and r_2, equal elastic moduli ϕ, and for which the factor of lateral contraction may be assumed as $m = 10/3$, Hertz has it that:

a The distance $\frac{\delta}{2}$ through which the bodies approach one another normally to the pressure surface under the load P; that is, the compression is

$$\frac{\delta}{2} = 1.23\sqrt[3]{P^2\,\alpha^2\,\frac{r_1 + r_2}{r_1\,r_2}} \qquad [1]$$

b The radius of the pressure surface, is

$$a = 1.11\sqrt[3]{P\,\alpha\,\frac{r_1\,r_2}{r_1 + r_2}} \qquad [2]$$

c The maximum pressure, which acts at the center of the pressure surface, is

$$p_0 = 0.388\sqrt[3]{\frac{P}{\alpha^2}\left(\frac{r_1 + r_2}{r_1\,r_2}\right)^2} \qquad [3]$$

From this it follows that the pressure p_0 is 1.5 the average pressure.

7 But the central elements of the pressure surfaces are not only compressed normally to the surface, but also in the other two directions. For circular pressure areas the principal stresses in the tangential plane are, according to Hertz, $(0.5 + 1/m)$ times the normal stress, with $1/m = 0.3$, and therefore $0.8\,p_0$.

8 Hertz carried out a number of experiments with glass in order to prove the agreement between practical results and his deductions. He showed, by pressing a glass lens against a plane disk of similar glass, that the diameters of the pressure surfaces increased as the cube roots of the pressures. To determine the influence of the elastic modulus, he pressed a steel lens against the plane surfaces of various metals, but encountering difficulties of observation he gave up the experimental proof.

9 Later, Auerbach by also pressing lenses against plane disks using three varieties of glass and one mountain crystal and measuring the compression areas, confirmed the relation of the compression area, diameter, load, and the lens curvature radius as previously investigated by Hertz.

10 His experiments, however, with various curved bodies of the same material gave no agreement of pressure at the elastic limit According to Hertz, passing the elastic limit in glass or other similar brittle substances first resulted in a circular crack closely following the edge of the pressure surface. The pressures causing these cracks were found to be dependent upon the curvature of the lenses, and invariably proportional to the cube roots of the ball surface diameters For ball and disk the load at the elastic limit was not found to be in accord with Hertz's formula, proportional to the square of the diameter, but proportional to the diameter. No conclusive explanation has yet been found for this phenomenon. Hertz himself did not consider it out of the question that the beginning of the elastic limit was dependent upon subsidiary influences, since he says: "The deductions greatly need an examination by practice, for it might be that actual bodies only remotely agree with our fundamental supposition of homogeneity. It is well enough known that the properties near the surface, which are those that here chiefly concern us, are frequently very different from those in the interior of the bodies."

11 So far there has been no basis from which to determine whether with metals also, the pressure at the elastic limit is dependent upon the surface curvature; yet this problem is important enough in general, and more especially so for the designer of ball bearings. Its solution will define the relation of the permissible load to the curvature of the bodies in contact. The clearing of this problem, at least for hardened cast steel, was therefore a prime consideration. It was also to be considered that since Equation 3 gives, for ball on disk,

that
$$\frac{1}{r_2} = 0 \text{ and } 2\,r_1 = d$$

$$p_0 = 0.388 \sqrt[3]{\frac{4\,P}{\alpha^2\,d^2}} \qquad [3a$$

with
$$\alpha = \frac{1}{2{,}120{,}000} \text{ (by trial)}$$

this gives

P =	d^2	$2\,d^2$	$3\,d^2$	$4\,d^2$	$5\,d^2$	$10\,d^2$	$50\,d^2$	$100\,d^2$
p_0 =	10,160	12,810	14,660	16,140	17,380	21,900	37,450	47,180 kg.cm

12 As a matter of fact this equation holds good only so long as the limit of proportionality of the bodies is not exceeded at any point. For the center of the pressure surface, where the greatest pressure exists, the chief stresses may be calculated by the Hertz method. It is only the largest one, normal to the surface, which concerns us and which amounts to 0.52 of the stress which p_0 alone would cause, since the existence of three main forces p_0, 0.8 p_0 and 0.8 $p_0 (1-2 \times 0.8 \times 0.3) \alpha p_0 = 0.52 \alpha p_0$.

13 If the elongation be accepted as a measure of the stress the material is subjected to, the limit of proportionality is in this case reached with a pressure which is

$$\frac{1}{0.52} = 1.92$$

times as great as that found by compression tests on a prismatic object.

14 It is assumed, of course, that the availability of Equation 3 for the proportionality is confirmed by experience. Two compression tests made with ball steel cylinders hardened in water, gave a limit of proportionality of 9000 kg. per 1 cm.[2]

15 For a ball and disk of hardened ball steel, Equation 3 gives the load at the beginning of the limit of proportionality in round figures $P = 5\ d^2$.

16 It is not to be expected that these relations hold also for greater loads. If one were, however, to take the permissible loads in ball bearings low enough not to exceed the elastic limit, that would be tantamount to giving up the use of ball bearings for heavy loads. This gave as a further problem the determination of the deformations under higher loads for which the third assumption of the Hertz equation does not hold, and to measure the elastic compression as well as the permanent set.

EXPERIMENTS ON THE COMPRESSION OF HARDENED STEEL BALLS AND DISKS

17 As previously mentioned, for the few experiments that were made to prove the Hertzian equations, the diameters of the compression surfaces were measured. This proceeding is not applicable to the present investigation, as it does not give any information on the permanent deformation. Aside from this it was, however, not practicable after each of the many loadings to separate the test pieces for a microscopic examination of the pressure surfaces. The difficulty was increased by the need of measuring the elastic recovery, which is

very much in evidence with hardened steel. For these reasons the compressions of the test pieces were measured; Hertz's Equation 1 is applicable to these.

18 In accordance with their object, the experiments were made on hardened cast steel. This material is peculiarly suitable to prove Hertz's equation since its limit of proportionality is high, so that relatively heavy loads may be employed.

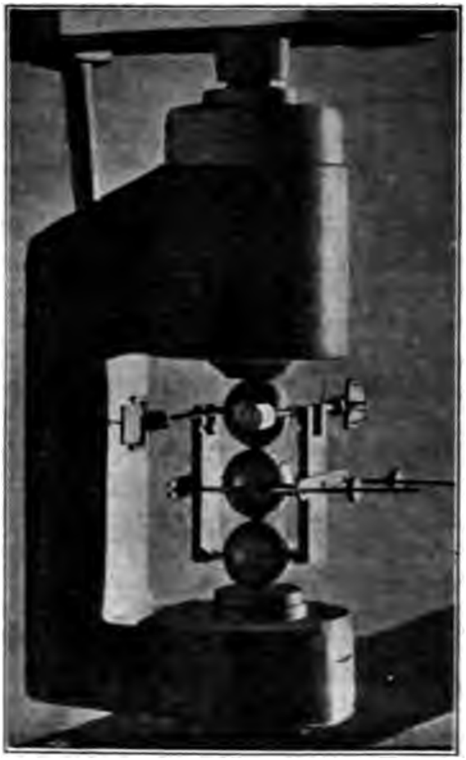


FIG. 1 COMPRESSION MEASURING DEVICE

19 On the other hand, many difficulties were to be expected in the determination of the compressions beyond the elastic limit. The compression is in a large measure dependent upon the hardness of the test-piece, and the necessarily large number of test pieces would scarcely be uniformly hard. To get good average results, each test series would have to be oft repeated with new specimens. Happily, the balls furnished by the German Small Arms and Ammunition

Factories varied but slightly in hardness, so that no inequalities of moment were found in compiling the results.

20 Hertz's second assumption that "there must be no forces except such as act normally upon the surfaces in contact," is not complied with by the older procedure of pressing a ball against a flat plate, since, with the exception of those at the center, the surface elements in contact are subject to different stresses and, therefore, tend to glide over one another, which they could do only by overcoming friction. But this second condition is fulfilled when balls of similar material and size are pressed together. This condition was, therefore, investi-

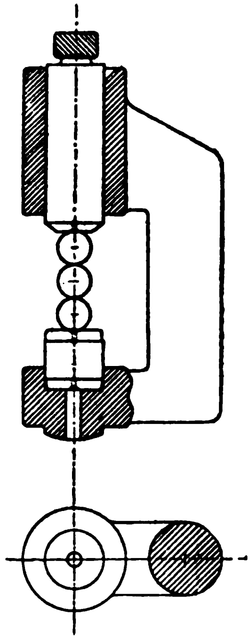


FIG. 2 DEVICE FOR MEASURING DEFORMATION

gated first. Later on balls were also pressed against flat plates. This gave two groups of test results, each of which could serve for the determination of the dependence of the load at the elastic limit upon the ball diameter.

21 The compression of the test pieces was measured with a mirror apparatus as designed by Martens. For the first group of experiments three balls were set one on the other. The knife edges of the measuring bars were attached at the half height of one outer ball and the knife edges of the mirrors were similarly attached to the other outer ball as shown in Fig. 1.

22 The measured distance, therefore, included two pairs of compression surfaces, so that the compression of two test bodies was measured. This permitted the determination of smaller impressions than with a single arrangement, which was particularly important for the very small permanent sets; this further permitted the reduction of the test series in that the measured values themselves corresponded to the average for two test pieces. The handling of the larger measuring bars was also much easier than that of the shorter ones for the single arrangement.

23 Dr. Amsler, with whom I talked about my intention to superpose these balls for measurement of the deformation, and who was, therefore, induced to take the matter up, after some time supplied me with an appliance substantially as shown by Fig. 2.

FIG. 3
GUIDES FOR ALIGNMENT OF BALLS

24 The two outer balls were located in this holder by small conical depressions. The center ball was aligned with the outer ones by means of one straight and one angular guide, Fig. 3. Amsler provided a pair of pliers with similarly formed jaws for the simultaneous insertion of these balls, which was useful with small balls.

25 To secure a firm attachment of the knife edges to the outer balls, small tubes of brass were cemented to the latter against which the knife edges were set. Double readings were taken, one on each side of the balls.

26 In the tests of balls on plates, a cylindrically turned disk was set between the two balls as shown by Fig. 4. Its thickness was equal to or greater than a ball radius. These disks were of the same material and were hardened in the same way as the balls.

27 Deformations were magnified 500 times, and the observed compression therefor corresponded to the average compression of one test piece pair under a magnification of one thousand. The apparatus described was used in a 5-ton Amsler testing machine.

28 The test pieces were alternately loaded and released. This was repeated for each load value until the compression was constant. At first the load on the upper piston of the ball holder was taken off completely so that the only weight on the balls was that of this piston. It was found, with the smaller loads under which permanent com-

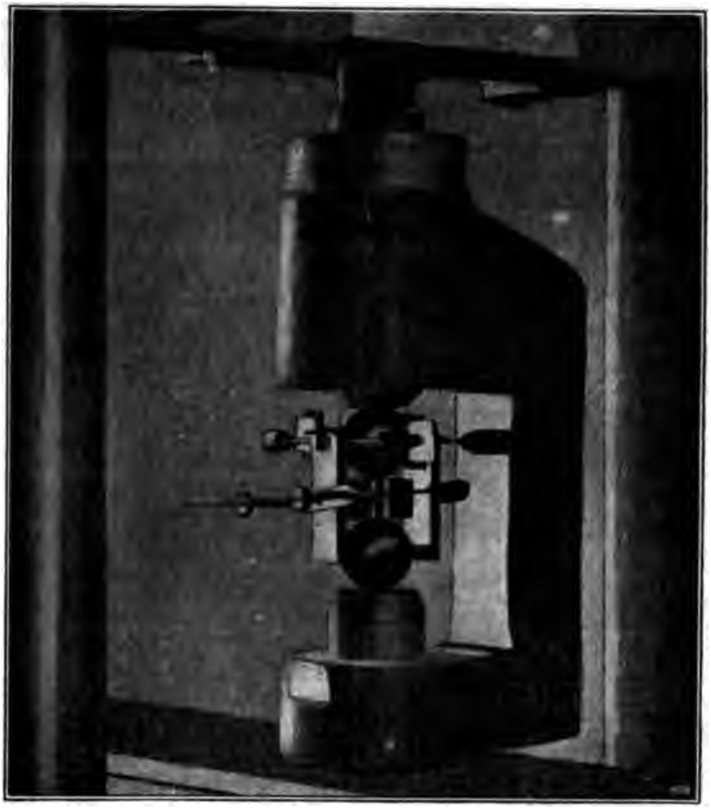


FIG. 4
TESTING BALLS IN CONTACT WITH FLAT SURFACES

pressions could not be definitely proved that the test values were in almost absolute accord with those found by calculation.

29 Since such complete release of the load readily caused disturbances, the lower load limit was, in view of the experience just cited, taken higher, generally 20 or 50 kg. The compression due to this load is determined by Equation 1.

30 The tests were carried out on balls ranging from $\frac{3}{8}$ to $\frac{9}{8}$ English inches. The results are given in Table 1 and 2.

TABLE 1

3 Balls of 3/8 Inch in Line

By equation 1 $\frac{\delta}{2} = 0.00012025 \sqrt[3]{P^2}$

Compression in hundredths of a millimeter

	P in kg. =	50	100	200	300	400	500	600	700	800
δTotal	by equat'n 1	3.26	5.18	8.22	10.78	13.06	15.15	17.11	18.96	20.73
	observed...	3.32	5.41	9.17	11.82	14.62	17.31	19.71	22.21	24.54
	averaged...	3.32	5.42	8.87	11.90	14.66	17.31	19.84	22.30	24.65
See Fig. 6 and 7										
δ_b Set	observed...	0.06	0.27	0.95		3.01		5.30		7.80
	averaged...	0.07	0.27	0.90	1.74	2.74	3.85	5.06	6.28	7.80

3 Balls of 1/2 Inch in Line

By equation 1 $\frac{\delta}{2} = 0.0001092 \sqrt[3]{P^2}$

	P in kg. =	100	200	300	400	500	600	700	800
δTotal	by equation..	4.71	7.47	9.79	11.86	13.76	15.54	17.23	18.83
	observed.....	4.83	7.81	10.33	12.83	14.98	17.33	19.14	21.14
	averaged.....	4.85	7.85	10.49	12.88	15.10	17.25	19.28	21.21
δ_b Set	observed.....	0.18	0.51	1.34	1.72		3.09		4.68
	averaged.....	0.18	0.56	1.10	1.72	2.45	3.26	4.12	5.06

3 Balls of 5/8 Inch in Line

By equation 1 $\frac{\delta}{2} = 0.0001014 \sqrt[3]{P^2}$

Compression in hundredths of a millimeter

	P in kg. =	50	100	200	300	400	500	600	700	800
δTotal	by equation .	2.75	4.37	6.94	9.09	11.01	12.78	14.43	15.99	17.48
	observed	2.78	4.44	7.14	9.45	11.65	13.62	15.49	17.42	
	averaged	2.78	4.43	7.13	9.51	11.65	13.63	15.53	17.35	19.08
δ_b Set	observed......	0.05	0.11	0.39	0.66	1.01	1.51	2.17	2.81	
	averaged	0.05	0.11	0.35	0.68	1.14	1.63	2.19	2.81	3.45

3 Balls of 3/4 Inch in Line

By equation 1 $\frac{\delta}{2} = 0.0000954 \sqrt[3]{P^2}$

Compression in hundredths of a millimeter

	P in kg. =	100	200	300	400	500	600	700	800
δTotal	by equation .	4.11	6.53	8.55	10.36	12.02	13.58	15.05	16.45
	observed	4.11	6.68	8.86	10.82		14.39		17.72
	averaged	4.12	6.62	8.79	10.76	12.59	14.31	16.00	17.58
δ_b Set	observed		0.22	0.50	0.85		1.61		2.69
	averaged ...		0.22	0.46	0.78	1.12	1.52	2.00	2.48

3 Balls of $\frac{7}{8}$ Inch in Line

By equation 1 $\frac{\delta}{2} = 0.0000907\sqrt[3]{P^2} = 1814$

Compression in hundredths of a millimeter

	P in kg. =	100	200	300	400	500	600	700	800
δ Total	by equation	3.91	6.20	8.13	9.84	11.42	12.90	14.30	15.63
	observed	3.93	6.22	8.19		11.75		14.96	16.44
	averaged	3.91	6.22	8.23	10.09	11.79	13.38	14.92	16.38
δ_b Set	observed			0.23		0.64			1.78
	averaged		0.15	0.30	0.55	0.79	1.10	1.42	1.80

3 Balls of 1 inch in Line

By equation 1 $\frac{\delta}{2} = 0.0000867\sqrt[3]{P^2} = 1734$

Compression in hundredths of a millimeter

	P in kg. =	100	200	300	400	500	600	700	800
δ Total	by equation	3.74	5.39	7.77	9.42	10.93	12.34	13.67	14.95
	observed	3.74	5.94	7.86	9.56		12.67	14.11	15.50
	averaged	3.74	5.94	7.84	9.59	11.21	12.70	14.13	15.50
δ_b Set	observed		0.12	0.22	0.39		0.70		1.28
	averaged		0.10	0.21	0.37	0.55	0.77	1.00	1.25

3 Balls of $1\frac{1}{8}$ Inch in Line

By equation 1 $\frac{\delta}{2} = 0.0000834\sqrt[3]{P^2} = 1668$

Compression in hundredths of a millimeter

	P in kg. =	100	200	300	400	500	600	700	800
δ Total	by equation	3.59	5.70	7.47	9.05	10.50	11.86	13.14	14.37
	observed	3.60	5.80	7.51	9.24	10.74	12.20	13.45	14.83
	averaged	3.59	5.70	7.52	9.20	10.75	12.18	13.53	14.83
δ_b Set	observed		0.06	0.15	0.22	0.38			0.90
	averaged		0.08	0.15	0.25	0.37	0.52	0.70	0.90

TABLE 2

Flat Disk Between Two ⅜ Inch Balls

By equation 1 $\frac{\delta}{2} = 0.0000954 \sqrt[3]{P^2}$

Compression in hundredths of a millimeter

	P in kg. =	50	100	200	300	400	500	600	700	800
δTotal	Hertz	2.59	4.11	6.53	8.55	10.36	12.02	13.58	15.04	16.45
	observed	2.64	4.15	6.62	8.57	10.54		14.18		17.59
	averaged	2.60	4.14	6.67	8.86	10.82	12.64	14.32	15.91	17.44
δ_b Set	observed		0.18	0.48	0.88	1.29		2.57		3.78
	averaged		0.18	0.48	0.86	1.33	1.86	2.48	3.12	3.81

Flat Disk Between Two ½ Inch Balls

By equation 1 $\frac{\delta}{2} = 0.0000867 \sqrt[3]{P^2}$

Compression in hundredths of a millimeter

	P in kg. =	50	100	200	300	400	500	600	700	800
δTotal	Hertz	2.35	3.74	5.92	7.77	9.42	10.93	12.34	13.68	14.95
	observed	2.37	3.78	6.04	8.04	9.68	11.40	12.77		15.60
	averaged	2.35	3.76	6.07	8.03	9.80	11.41	12.98	14.45	15.75
δ_b Set	observed		0.12	0.31	0.63	0.80	1.20	1.48		2.26
	averaged		0.12	0.33	0.60	0.89	1.21	1.6	2.00	2.46

Flat Disk Between Two ⅝ Inch Balls

By equation 1 $\frac{\delta}{2} = 0.0000805 \sqrt[3]{P^2}$

Compression in hundredths of a millimeter

	P in kg. =	50	100	200	300	400	500	600	700	800
δTotal	Hertz	2.19	3.47	5.51	7.22	8.74	10.14	11.45	12.69	13.84
	observed	2.27	3.68	5.70	7.47	9.03	10.43	11.78	13.01	14.31
	averaged	2.19	3.50	5.64	7.40	9.04	10.54	11.93	13.23	14.46
δ_b Set	observed			0.18	0.39	0.62	0.78	1.08	1.16	1.44
	averaged			0.23	0.44	0.64	0.85	1.13	1.39	1.63

Flat Disk Between Two ¾ Inch Balls

By equation 1 $\frac{\delta}{2} = 0.0000720 \sqrt[3]{P^2}$

Compression in hundredths of a millimeter

	P in kg. =	100	200	300	400	500	600	700	800
δTotal	Hertz	3.10	4.92	6.45	7.81	9.07	10.24	11.34	12.40
	observed	3.12	5.04	6.63	8.03	9.44	10.56		12.90
	averaged	3.11	5.02	6.59	8.03	9.40	10.60	11.75	12.87
δ_b Set	observed		0.09	0.18		0.41			0.90
	averaged		0.10	0.21	0.34	0.49	0.61	0.79	0.95

FLAT DISK BETWEEN TWO [illegible] INCH BALLS

By equation 1 $\frac{\delta}{2}=0.0000662\sqrt[3]{P^2}$

Compression in hundredths of a millimeter

	P in kg. =	100	200	300	400	500	600	700	800
δTotal	Hertz........	2.85	4.53	5.93	7.19	8.34	9.42	10.44	11.41
	observed	2.87	4.55	5.95	7.29		9.67		11.71
	averaged	2.85	4.54	5.98	7.28	8.48	9.60	10.65	11.68
δ_b ε .t	observed		0.07	0.17	0.24		0.48		0.67
	averaged			0.12	0.19	0.29	0.39	0.50	0.62

31 For each ball size the table gives the compression in hundredths of a millimeter under various loads.

The expressions for

$$\frac{\delta}{2}$$

at the head of each table are derived from Equation 1 with

$$\alpha = \frac{1}{2,120,000}$$

It forms the basis of the first line of compressions, which therefore are applicable only under the conditions of this equation. Since the limit of proportionality is exceeded with even the lowest loads cited, a deviation of these calculated values from the observed ones is to be expected, increasing with the loads.

32 Below these are given in the tables the observed and the average total compressions as well as the corresponding permanent sets.

33 The elastic modulus was determined by compressing cylinders of 16 mm. in diam. and 48 mm. in length. The measuring length was 32 mm.

34 As the available data concerning the influence of the hardening process on the material under test, or of the hardness on the elastic modulus, were incomplete and insufficient, the tests were extended to steel cylinders hardened in oil, hardened in water, and unhardened. As the behavior beyond the elastic limit also merits consideration that also was observed within the limitations of the mirror apparatus. The elastic recovery, which was the more noticeable the farther one was from the limit of proportionality, is included, notwithstanding the extraordinary labor resulting from its consideration.

35 The observed moduli of elasticity were found to be

for the unhardened cylinder $\alpha = \frac{1}{2,127,000}$

for the oil hardened cylinder $\alpha = \frac{1}{2,128,000}$

for the water hardened cylinder $\alpha = \frac{1}{2,102,000}$

36 The difference in round figures between the lowest and highest values is 5/4 per cent. Since, with the short length measured, errors of observation of this amount are not impossible, and since the elastic modulus for the oil hardened cylinder was found to be almost identical with that for the unhardened one, the average of all these observations was taken as the probable value for the water hardened cylinder as well. This is, in round figures,

$$\frac{1}{2,120,000}$$

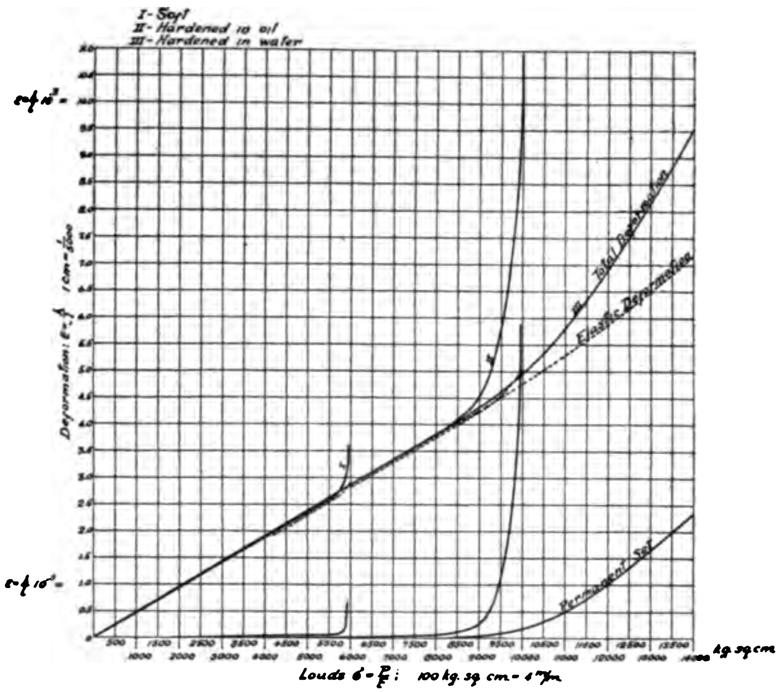


FIG. 5 BALL STEEL SUBMITTED BY THE DEUTSCHE WAFFEN UND MUNITIONS FABRIKEN, BERLIN

COMPRESSION TESTS WITH CYLINDERS OF 16 MM. DIAM. 48 MM. LENGTH. MEASURED DISTANCE, 32 MM.

38 Beyond the limit of proportionality the various steel cylinders act very differently. See Fig. 5. While with the unhardened cylinder the permanent set rapidly increases, and while a limit of flow even is indicated, and with the oil hardened cylinder the compres-

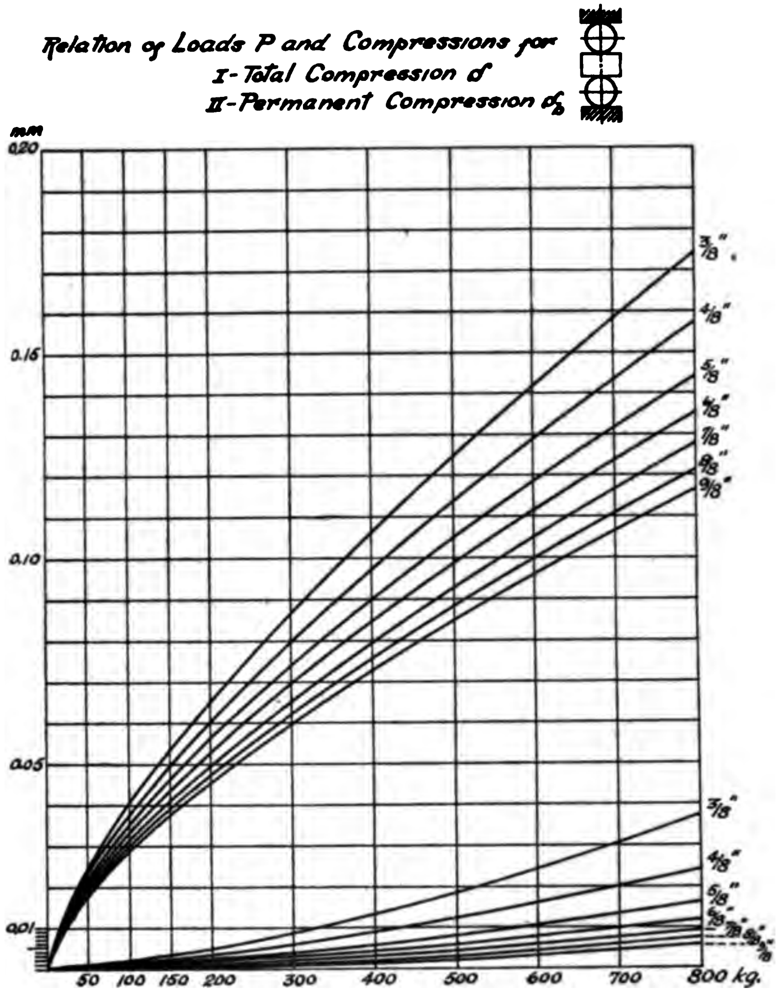


FIG. 6 COMPRESSION FOR DIFFERENT LOADS

sion curves after a sharp bend trend steeply upward, with the water hardened cylinder the rise is slow.

39 Since the compressions for two test pieces were measured together the value δ was inserted in the table. The compression of the

individual test piece was therefore only one-fourth of the tabular value.

40 The difference between the total and the permanent compression gives the elastic compression.

41 The total compressions are greater beyond the elastic limit, but the elastic compressions are smaller than the values calculated from Equation 1. It is, however, readily seen, that even after the proportional limit is considerably exceeded, the differences are not material. This follows clearly from Fig. 14.

42 The average compressions are those derived by plotting as coördinates those values of d and δ, d and δ_b, as well as P and δ and P δ_b, respectively, that belong together, as is shown graphically by Fig. 6 to 8 and 10 to 12.

43 This averaging may be more completely carried through mathematically, but the greater complication and lesser oversight of this method is not sufficiently compensated for.

44 In the experiments with these superposed balls, the average compressions really vary but slightly from the observed. The differences are particularly small with the total compressions, though rather greater with the permanent sets. Where the observed values are generally greater than the averaged ones, it is fair to assume that the balls are somewhat softer than the average and that they are rather harder when the observed values remain under the average ones. Errors arise chiefly from the balls not only approaching, but also rolling off of one another. This occurs when the outer balls do not seat themselves fairly in their seats in the pistons, possibly because the centers of the three balls do not lie in the same straight line, so that the load does not act through the centers of the circular contact surfaces. It is not always easy to avoid these sources of error; the difficulties increase with the size of the balls. Disturbances may also be due to the pressure piston turning slightly as it is loaded or unloaded.

45 The differences between the observed and the averaged compressions are greater for ball and disk, this applying more particularly to the permanent deformations. The difficulties of the test were greatly increased by differences in the hardness of the disks and because the suitability of the disks could be determined only in the course of the test. Most of the disks were too soft, while a few were too hard.

THE LOAD AT THE ELASTIC LIMIT AND ITS RELATION TO THE BALL DIAMETER

46 In Fig. 6 and 10 the curves relating to the permanent set touch the axis of the abscissae near the origin. In reality neither these points of contact, nor yet the trend of the curves in their neighborhood, can be determined with certainty. Therefore the loads at the elastic limit cannot be deduced from these tests; nevertheless their dependence upon the ball diameters may be determined by a course of reasoning as follows: If surface stresses or other not yet known causes produce changes in the elastic limit such that the compressions at the elastic limit are dependent upon the curvature of the test piece—as Auerbach found for the brittle test pieces he examined—then these subsidiary phenomena cannot cease suddenly when the elastic limit is reached. Even with the cylindrical test piece the elastic limit is not a sharply defined characteristic point in the compression, still less is it so for two balls in contact.

47 Its advent does not make itself visibly manifest, since at first only a single element of the test piece is involved; only by raising the load is success had in stressing other elements to the elastic limit accompanied by a simultaneous increase of the pressure surface so that new surface elements are placed under elastic strain. Subsidiary influences will, therefore, in so far as they exist at all, certainly extend beyond the elastic limit. Auerbach reports also on experiments with plastic bodies in which the greatest attainable pressure also shows its dependence upon the curvature, generally accompanied by considerable permanent compression. For these greatest pressures Auerbach found the same dependence upon the curvature of the object that he gives for the elastic limit of brittle bodies.

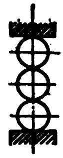
48 The test method employed and about to be described is based on these general considerations and experiences.

The elastic limit is defined by the permanent deformation amounting to a small part $\varDelta$, of the total deformation, such part differing but slightly from zero; If δ_b' and δ' are the deformations at the elastic limit, then

$$\frac{\delta_b'}{\delta} = \varDelta$$

or, inserting the ball diameter d

$$\frac{\delta_b'}{d} : \frac{\delta'}{d} = \varDelta$$

Relation of Ball Diameter d and Total Compression δ for 

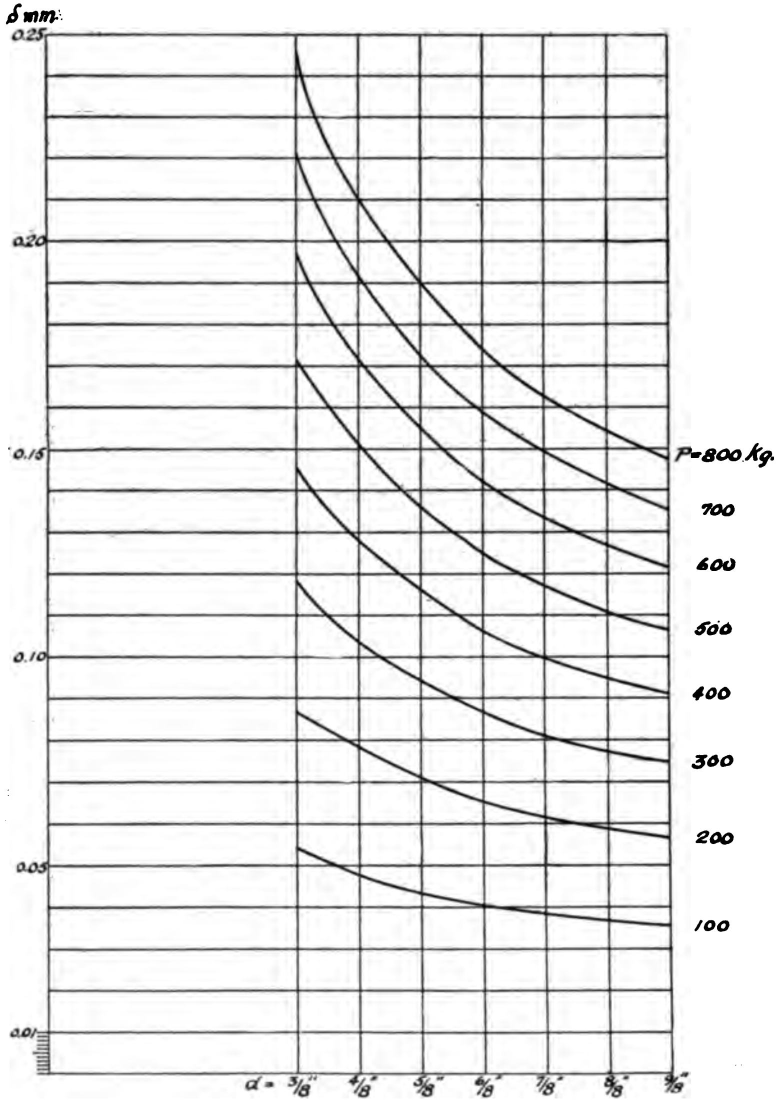


FIG 7. TOTAL COMPRESSION FOR DIFFERENT DIAMETERS

49 This expression we apply to small but sufficiently accurately measurable permanent deformations δ_b which belong to the total deformations δ while examining into the conditions under which $\frac{\delta_b}{d}$ as well as $\frac{\delta}{d}$ are constant. We shall assume that for $\frac{\delta_b}{d}$ = constant there exists the relation $P = k\ d^2$, k being the constant. Logically the same loads apply to δ and δ_b. The total deformations δ must therefore also be caused by loads $P = k\ d^2$. This condition, by Equation 1, results in $\frac{\delta}{d}$ = constant, which would be exactly true only at the limit of proportionality. For

$$P = k\ d^2$$

therefore also

$$\frac{\delta_b}{\delta} = \text{constant.}$$

50 But we know that in the absence of surface stresses and other subsidiary influences it must be that

$$P = k'\ d^2$$

at the elastic limit. Since the expression

$$P = k\ d^2$$

for which there would exist a deformation relation similar to that for the elastic limit, differs only in the constant factor, it may be deduced that, should our assumption hold true, surface strains do not exist with the introduction of the load and therefore do not exist at the elastic limit. We should then be justified in assuming as a fact that at the elastic limit $P = k'\ d^2$ and that the deformations for various ball diameters are the same.

51 The series of curves of Fig. 8 and 12 are suitable for this investigation. We shall first extend them to the contact of balls of the same size, as in Fig. 8, and select

$$\frac{\delta_b}{d} = 0.00025$$

so that the permanent compression of one ball is

$$\frac{\delta_b}{4} = 0.0000625\ d$$

52 In order to get the loads which for various ball diameters cause

the permanent sets $\delta_b = 0.00025\,d$ we draw a diagonal $\frac{\delta_b}{d} = 0.00025$ through the curves of Fig. 8. The abscissa of each intersection gives us a diameter. The corresponding load is noted at the curve intersected. If now the squares of these diameters and the curves corresponding to them are plotted as coördinates and the points connected, a fairly straight line passing through the origin is given, as in Fig. 9. For since

$$\frac{\delta_b}{d} = 0.00025$$

it is true that

$$P = k\,d^2$$

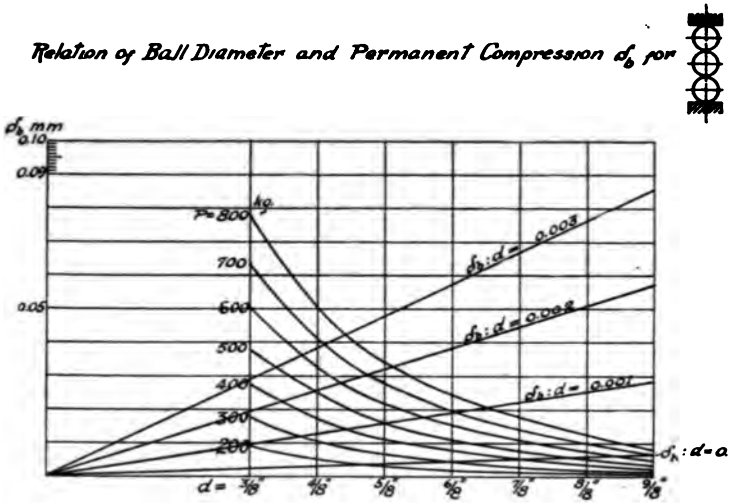


FIG. 8 PERMANENT COMPRESSION FOR DIFFERENT DIAMETERS

53 Citing the numerical value found we get from Fig. 8

for P in kg. =	200	300	400	500	600	700
d in inches =	0.600	0.740	0.869	0.966	1.051	1.125
therefore $\frac{P}{d^2}$ =	556	547	530	536	545	553

54 Fig. 9 also gives the results of the investigation for some larger values of $\frac{\delta_b}{d}$. We see that the smaller $\frac{\delta_b}{d}$, the less the curves deviate from diagonals starting from the origin, that is to say, the nearer we get to the elastic limit.

55 The investigation of ball and disk gives the same result, as is shown in Fig. 13. We have, for instance,

$$\frac{\delta_b}{d} = 0.000125$$

for which the permanent compression of one test object is 0.000031 d, and the corresponding values are

P in kg.	= 200	300	400	500	600
and d in inches	= 0.644	0.787	0.912	1.019	1.112
so that $\frac{P}{d}$	= 482	485	481	482	485

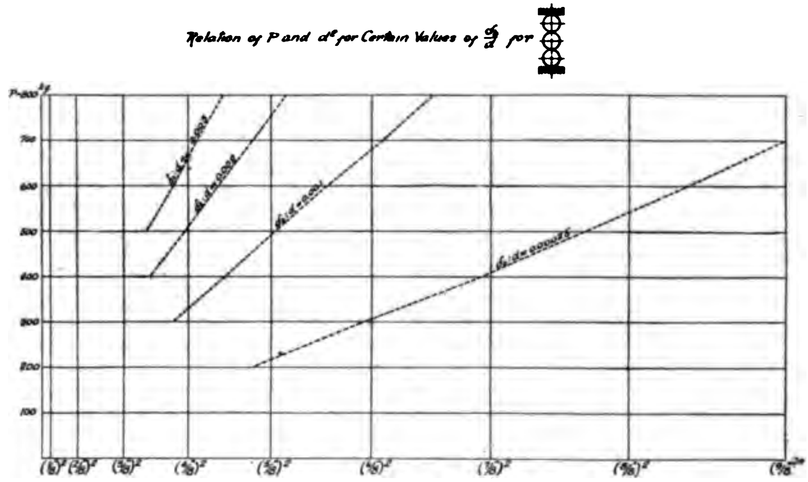


FIG. 9
DIAGRAM DEVELOPED FROM FIG. 8

56 It is therefore proved that for balls of the hardened steels employed in these investigations, *at the elastic limit, the loads are proportional to the squares of the diameters and that therefore the deformations are equal for all ball diameters.* (Translator's Note: Since, see Table, compression $\frac{P}{d^2}$ is constant.)

THE EQUATION FOR THE PERMISSIBLE LOAD

57 From what has been said important conclusions may be drawn concerning the permissible load. Although other points of view which remain to be considered may be of influence, there are to b

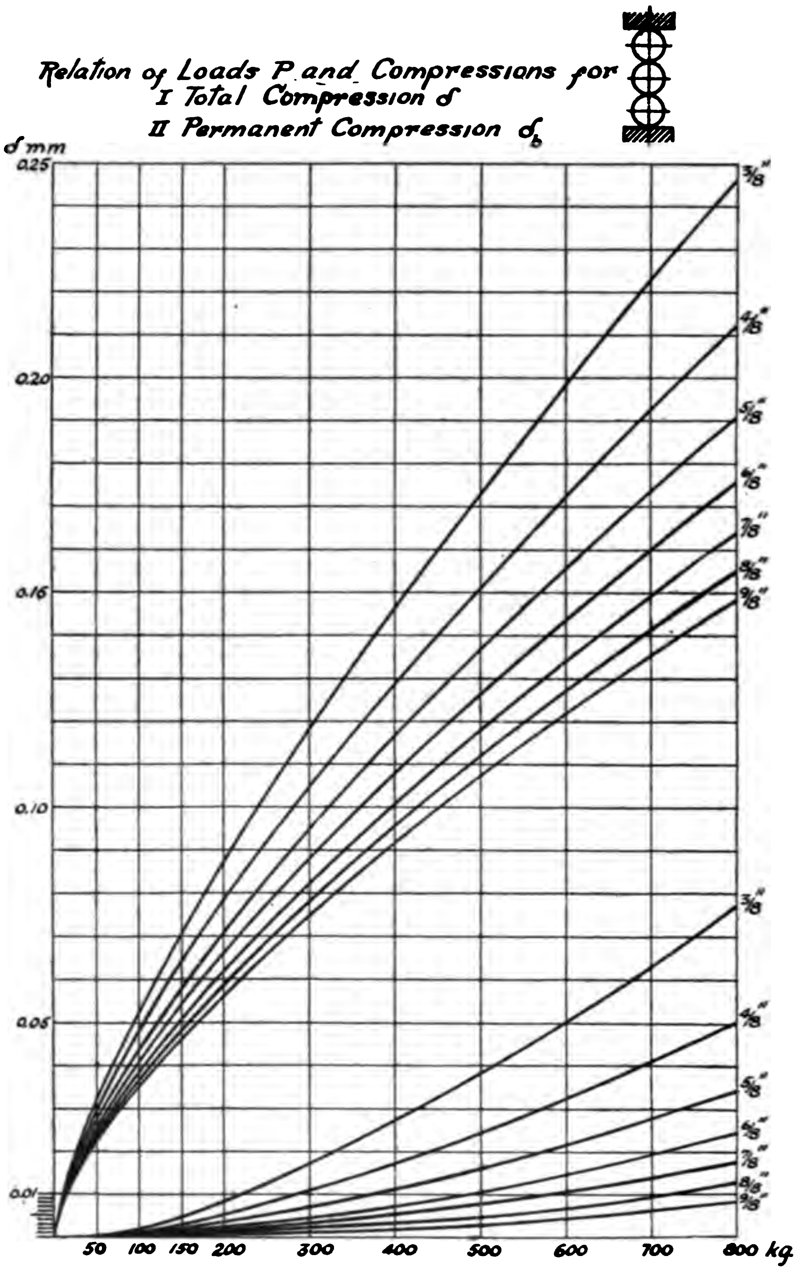


FIG. 10 COMPRESSION FOR DIFFERENT LOADS

taken into account chiefly the greatest stress on the bodies, the pressure at the compression surfaces and the stress ratio $\delta_b : d$. We have been informed concerning the dependence of these values upon the load at the elastic limit as well as beyond that. Since these values, sometimes one sometimes another of which may determine the permissible load, are equal for various ball diameters so long as a

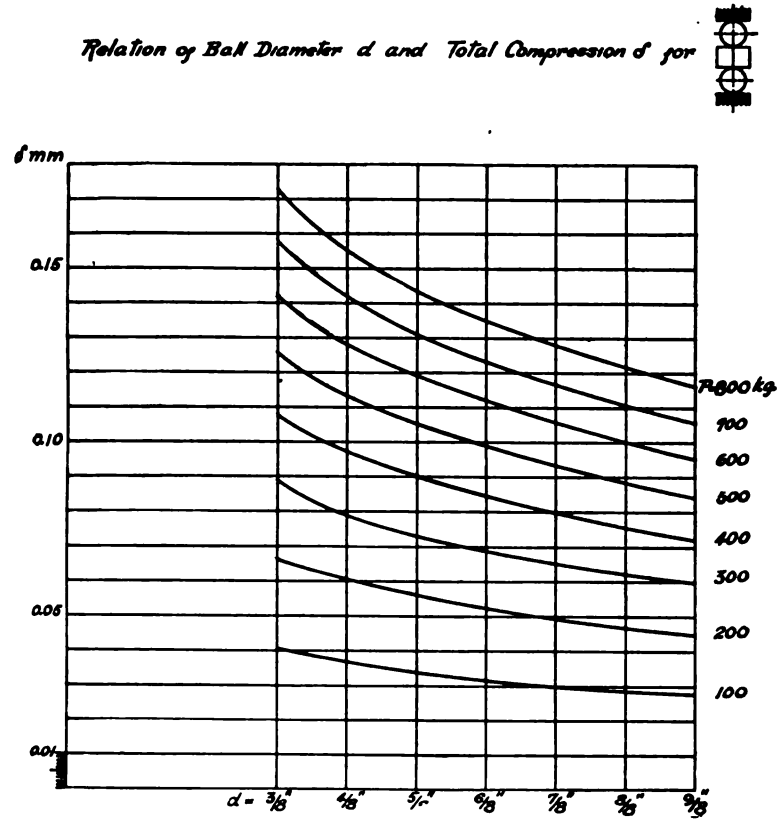


FIG. 11 TOTAL COMPRESSION FOR DIFFERENT DIAMETERS

selection is made which gives $\frac{P}{d^2}$ = constant, for all these cases

$$P = k\,d^2 \qquad [4]$$

may be used as a basis for calculations and P be taken as the permissible load; k is then the permissible load for a unit diameter or the permissible specific load.

58 It is desirable to prove this relation, which has been derived

from the occurrences under static load, by actual experience with ball bearings. In any event such experiments had to be made in order to get data for k and the friction values. Chapter 6 reports such investigations. Attention is here merely drawn to the fact that they confirm the relation $\frac{P}{d^2}$ = constant.

59 From the results of the compression tests with balls and disk deductions may be drawn giving the amount of the permanent compression δ_b for various values of $\frac{P}{d^2}$. Before taking up the investigation of ball bearings, it appeared advisable to represent this relation

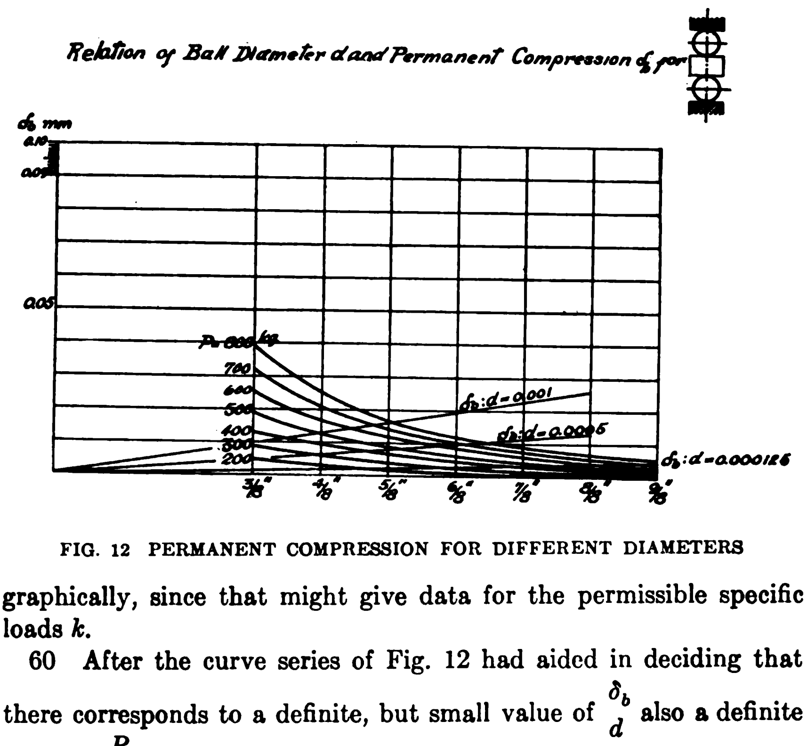


FIG. 12 PERMANENT COMPRESSION FOR DIFFERENT DIAMETERS

graphically, since that might give data for the permissible specific loads k.

60 After the curve series of Fig. 12 had aided in deciding that there corresponds to a definite, but small value of $\frac{\delta_b}{d}$ also a definite value of $\frac{P}{d^2}$, it became easy to determine, with the aid of the same series of curves, that particular value $\frac{\delta_b}{d}$ belonging to any value of $\frac{P}{d^2}$.

61 In the following table k is the permissible load in kg. for a diameter of $\frac{1}{8}$ inch English. In the equation $P = k d^2$ the unit for d is

therefore $\frac{1}{8}$ inch. The selection of this value as unity is justified because balls are manufactured to the English system of measurement while the formula may be readily transformed into cm. since, for

$$d \text{ in cm. } k = \left(\frac{1}{0.3175}\right)^2 = 9.92$$

or, in round figures, k is ten times as great as for eighths of an inch.

k in kg. per $\frac{1}{8}$ inch	=	4	5	7.5	10	15	20
$\frac{\delta_b}{d}$ .1000	=	0.047	0.067	0.125	0.204	0.374	0.555
$\frac{\delta}{d}$ .1000	=	2.24	2.61	3.41	4.14	5.50	6.65
$\frac{\delta_b}{\delta}$		0.021	0.026	0.037	0.049	0.068	0.083

62 This influence of k on the deformation is more clearly grasped from the graphic representation of Fig. 15. Note particularly the curve $k, \frac{\delta_b}{d}$. With the aid of curves $k, \frac{\delta}{d}$ and $k, \frac{\delta_b}{\delta}$ this curve may, with fair certainty, be determined almost to the origin. Since this curve comes in contact with the axis of the abscissae the permanent sets at first increase but slowly. With $k = 2$, δ_b is approximately $0.000015\,d$, and for each pressure point one-fourth of this. For instance, for $d = 20$ mm. 0.00008 mm. With $k = 4$ the compression is already three times and with $k = 6$, it is six times as large; with $k = 10$ the curve has almost reached its greatest inclination to the axis of the abscissae. Though this trend of the curve does not admit of definite conclusions, it may yet lead others, as it has me, to suppose that for a ball or disk or similar conditions k would lie between 2 and 6, and that 10 might be too high. One would have to conclude, not that the resultant change from sphericity would increase the resistance to motion, but rather that this extraordinary stressing of the material would sooner or later damage the parts and more particularly the races.

63 Should the experiment with ball bearings actually lead to k smaller than 6, that would indicate the advisability, at least for heavy loads, of so shaping the races that they present a larger supporting surface to the balls. For this reason $\frac{5}{8}$ inch balls were also pressed against grooved cylinders, as at the right in Fig. 14, whose groove radius of curvature was $\frac{2}{3}$ of the ball diameter. For equal loads and compressions within the limit of proportionality we calcuate, according to Hertz, the load for disk and ball is to that for cyl-

inder and ball as 1: 3.56. The ratio of the deformations approximates as 1: 5/3.

64 Beyond the limit of proportionality and within the region of permissible loads the difference in favor of the grooved cylinder and ball is rather smaller. A load 3.56 times as great would for grooved cylinder and ball give rather greater deformation and, more particularly, greater sets, than for balls on flat disks, as will be seen by comparing Fig. 14.

65 Nevertheless it is to be expected that the permissible load for hollow cylinder and ball is materially greater than for ball and plane disk. Conclusive data are also to be expected only from experiments with ball bearings, since balls and races are subject to further influences that come in with relative motion.

TABLE 3

COMPRESSION IN HUNDREDTHS OF A MILLIMETER FOR A GROOVED CYLINDER BETWEEN TWO BALLS OF ¾ INCH DIAMETER

According to Hertz $\frac{\delta}{2} = 0.000057 \sqrt[3]{P^2}$

	P in kg.=	50	100	200	300	400	500	600	700
δ	Hertz.........	1.55	2 46	3.90	5.11	6.19	7.18	8.11	9.82
	observed	1.59	2.56	4.11	5.39	6.51		8.48	10.21
δ_b	observed	0.01	0.06	0.13	0.18	0.25		0.40	0.57

THE FRICTIONAL WORK OF BALL BEARINGS

THE MOVEMENTS AND THE EQUATION FOR THE FRICTIONAL WORK

66 Assume that a ball moves between the surfaces of rotation of two ball races, of which each may present to the ball two supporting surfaces A_1 A_2 and B_1 B_2, but otherwise have any desired shape. See Fig. 16. The race A_1 A_2 is to revolve around its axis with reference to race B_1 B_2 at an angular velocity ω. The center A of distance A_1, A_2 is distant from the axis rotation by R. R is the mean radius of the rotation surface A_1 A_2. The velocity of point A is therefore $R\omega$.

67 The speeds which determine the frictional work are here to be chiefly considered. There must be taken into account the movements of the balls with relation to the race surfaces B_1 B_2 and A_1 A_2. The one has rotation around the instantaneous axis B_1 B_2 the other, rotation around A_1 A_2 as an instantaneous axis. Let the angular velocities of these rotations be ω_b and ω_a.

68 If there is to be no sliding at the centers of the supporting surfaces, then the three axes of rotation $W\ W$, $A_2\ A_1$, and $B_2\ B_1$ must either meet in one point or be parallel.

69 The ball center is distant from $B_1\ B_2$ by b and point A by e. Let ω_0 be the angular velocity with which the ball center rotates in a circle of radius R_0 around the axis $W\ W$ then

$$\omega_0 = \frac{R}{e}\ \omega$$

and also

$$\omega_b = \frac{R_0}{b}\ \omega_0 \qquad [5]$$

so that

$$\omega_0 = \frac{R}{R_0}\ \frac{b}{e}\ \omega$$

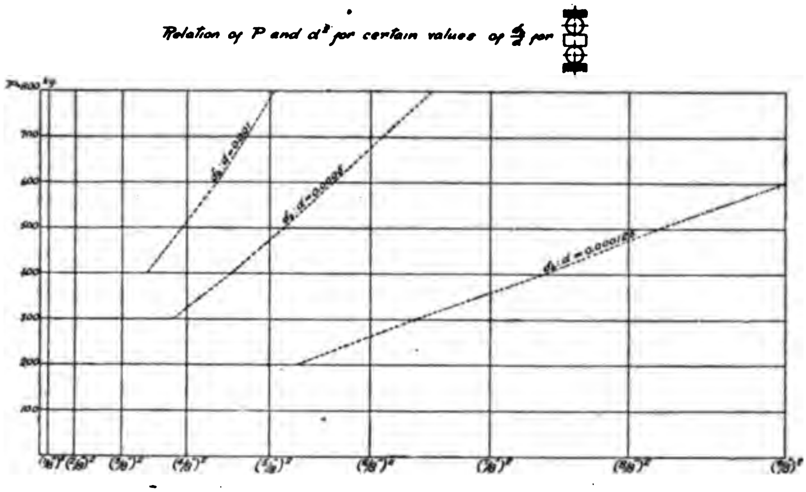


FIG. 13 DIAGRAM DEVELOPED FROM FIG. 12

70 The expression for ω_a is readily found if race $A_1\ A_2$ be considered stationary with the ball center rotating around axis $W\ W$ with the angular velocity $\omega_0 - \omega$. This is true since we have

$$\omega_a = \frac{R_0}{a}\ (\omega_0 - \omega)$$

and also

$$\omega_a = -\ \frac{R_0}{a}\ (\omega - \omega_0)$$

71 The minus sign indicates that this rotation and the rotation of race $A_1 A_2$ are opposed.

Replacing w_0 by its equation as found gives

$$\omega_a = - \frac{R_0}{a}\left(1 - \frac{R}{R_0}\frac{b}{e}\right)\omega \qquad [6]$$

72 A good conception of the velocity ratio is gained from the velocity parallelograms, by whose aid ω_a and ω_b may also be rapidly determined. These parallelograms are given in Fig. 16. They also give the angular velocity ω_e of rotation around axis $M\ C$.

73 Concurrently with the angular velocities the friction moments exist as factors of the frictional work.

74 The axes of rotation $A_1 A_2$, $B_1 B_2$ pass through the centers of the surfaces of rotation. All elements in the pressure surfaces of the ball have elementary rotation around these axes. To make this clear let us consider the occurrences at one pressure surface.

75 Let the axes of rotation form angles with the plane tangent to the center of the pressure surface as shown in Fig. 17; conceive the rotation divided into two elementary rotations, the one moving around an axis normal to the pressure surface and therefore at an angular velocity $\omega_b \sin \phi$, and the other around an axis lying in the contact surface and therefore at an angular velocity $\omega_b \cos \phi$.

a It is a fundamental condition for rotation around the normal axis with velocity $\omega_b \sin \phi$ that the elements in the pressure surface of ball and race slide on one another. The resultant friction may be considered as step friction. For its calculation the dimensions of the pressure area, which by the way is an ellipse, would have to be determined by Hertz's investigations and it be considered that, according to Hertz, the deformations increase from the edge toward the center, as do the ordinates of an ellipsoid erected over the pressure area ellipse.

b Rotation around the axis in the contact plane, whose angular velocity is $\omega_b \cos \phi$ is opposed by a resistance which may be called the rolling friction of the ball, but which also is not free of sliding friction.

76 Let B be the thrust load and let us express the moment of the step friction as

$$\mu\ B\ x$$

with μ the mean friction coefficient, x the mean friction radius, then the frictional work due to the ball rotating around an axis normal to the pressure surface with an angular velocity $\omega_b \sin \phi$ is

$$\mu\ B\ x\ \omega_b \sin \phi$$

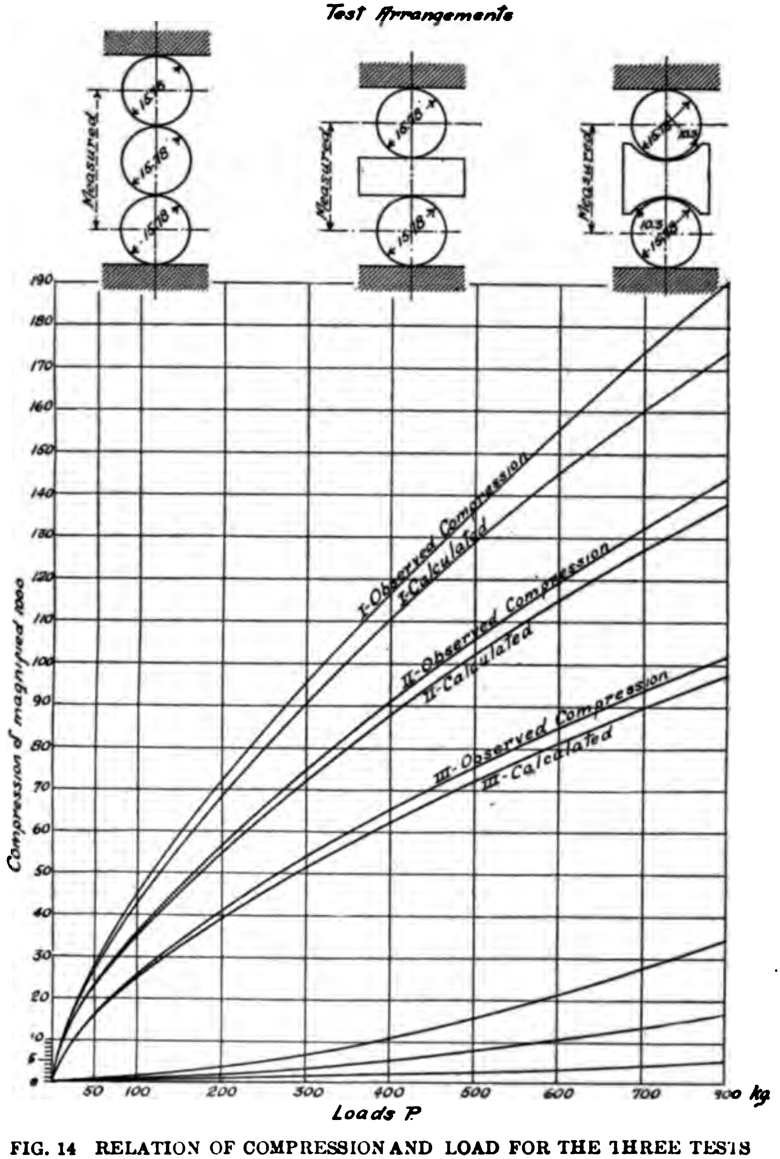


FIG. 14 RELATION OF COMPRESSION AND LOAD FOR THE THREE TESTS

1 3 balls ⅝" diam. in line. Compression according to Hertz $\frac{\delta}{2} = 0.0001014 \sqrt[3]{P^2}$

2 2 balls ⅝" diam. and flat disk. Compression according to Hertz $\frac{\delta}{2} = 0.000057 \sqrt[3]{P^2}$

3 2 balls ⅝" diam. and grooved cylinder. Compression according to Hertz $\frac{\delta}{2} = 0.000057$ $\sqrt[3]{P^2}$

Modulus of elasticity $= \frac{1}{2{,}120{,}000}$

77 Further let $B\,f$ be the moment of rolling friction so that f is the coefficient of rolling friction. The corresponding angular velocity of rotation is $\omega_b \cos \phi$ and therefore the frictional work for one pressure surface

$$\mu\, B\, x\, \omega_b \sin \phi + B\, f\, \omega_b \cos.\, \phi = B\, (\mu\, x \sin \phi + f \cos \phi)\, \omega_b$$

78 If there are four pressure surfaces and the corresponding loads A_1 A_2, B_1 B_2 and α and β the acute angles included between the axis

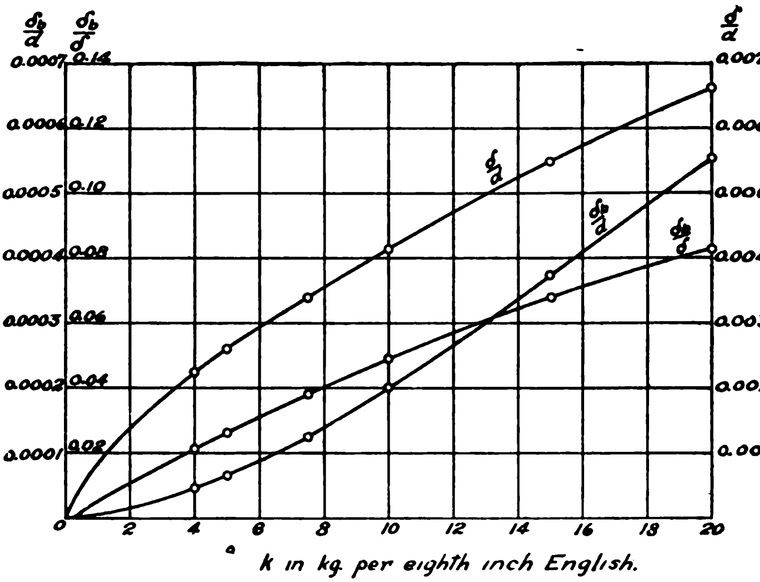


FIG. 15 RELATION OF DEFORMATION AND UNIT DIAMETERS

of rotation and the pressure surface, then the frictional work for the four pressure surfaces is

$$A_1\ (\mu_1\ x_1\ \sin \alpha + f_1\ \cos \alpha)\ \omega_a$$
$$A_1\ (\mu_2\ x_2\ \sin \alpha + f_2\ \cos \alpha)\ \omega_a$$
$$B_1\ (\mu_1'\ x'_1 \sin \beta + f'_1 \cos \beta)\ \omega_b$$
$$B_2\ (\mu_2'\ x'_2 \sin \beta + f'_2 \cos \beta)\ \omega_b$$

Their sum gives the total frictional work A_r.

As a rule it would be permissible to say:

$$\mu_1 = \mu_2 = \mu\,;\ \mu'_1 = \mu'_2 = \mu'$$
$$f_1 = f_2 = f\,;\ f'_1 = f'_2 = f'$$

so that

$$A_r = [(A_1\, x_1 + A_2\, x_2)\ \mu\ \sin \alpha + (A_1 + A_2)\ f\ \cos \alpha]\ \omega_a$$
$$+ [(B_1\, x'_1 + B_2\, x'_2)\ \mu'\ \sin \beta + (B_1 + B_2)\ f'\ \cos \beta]\ \omega_b \quad [7]$$

79 The long continued experiments with ball bearings which have been carried out in the Central Laboratory give information for the value of μ x and f. For the determination of the rolling friction f those bearings are particularly suitable for which α and $\beta = 0$, so that the step friction disappears.

80 In this case also

$$A_1 + A_2 = B_1 + B_2 = S$$

and therefore

$$A_r = Sf\omega_a + Sf'\omega_b \qquad [8]$$

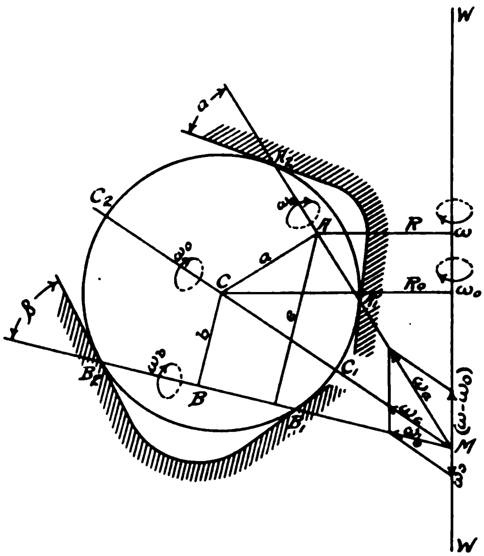


FIG. 16

f and f' will not be equal, since the ball makes contact with one race at the inner and with the other at the outer running surface. Nevertheless it is, for practical reasons, advisable to use

$$A_r = Sf\,(\omega_a + \omega_b) \qquad [8a]$$

and to consider f the mean coefficient of rolling friction. Since further

$a = b = \dfrac{e}{2}$ and $e = d$, it follows

first that
$$\omega_a = \frac{2\,R_o}{d}\,(\omega - \omega_o)$$

$$\omega_b = \frac{2\,R_o}{d}\,\omega_o$$

and therefore that

$$A_r = Sf\,\frac{2\,R_o}{d}\,\omega = Sf\,\frac{D_o}{d}\,\omega \qquad [9]$$

81 It is to be especially noted that the frictional work increases with the ratio $\frac{D_o}{d}$. To have it as low as possible the balls must rotate around the smallest circle.

82 If there is room for z balls in the race and if z is sufficiently large so that approximately

$$\pi\,D_o = z\,d$$

and therefore

$$\frac{D_o}{d} = \frac{z}{\pi}$$

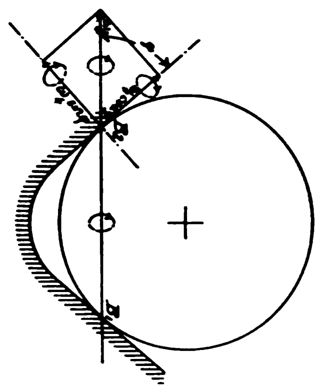


FIG. 17

then it may be said, for the case of the balls having only rolling motion that *the frictional work is smaller the fewer balls there are in a race.*

83 It may therefore prove advisable to start with the number of balls belonging to a pair of races

84 The above values apply to one ball only. The total friction of a bearing is the sum of the frictional work found for the individual balls. Since ω_a and ω_b and α and β have equal values for all balls, the rolling friction is calculated from the expression given for the individual ball, by inserting the sum of the loads of all balls for S. The rolling friction coefficient f is then to be taken as that for the bearing as a whole and not that of the individual ball. On the other hand, the calculation of the sliding friction is more complex, since the values of x are dependent upon the individual loads.

85 The first task therefore is the determination of the individual loads of a bearing as well as of the total loads on the balls of a bearing.

86 If P is that portion of a journal load carried by one ball row, then for the simple case of Fig. 18,

$$P = P_o + 2\ P_1 \cos \gamma + 2\ P_2 \cos 2\gamma + \ldots + 2\ P_n \cos n\gamma$$

in which

$$n\gamma < 90^\circ$$

and as a rule

$$\gamma = \frac{360}{z}$$

therefore

$$n < \frac{z}{4}$$

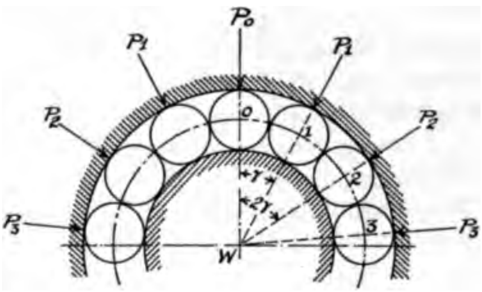


FIG. 18

87 Let δ_o be the approach of the two races in the direction of radius $W\ O$ under load P_o; the approaches $\delta_1\ \delta_2$, etc., correspond to P_1 P_2, etc.

88 If, before load is applied, there is no play between the balls and races and the races are not appreciably deflected under the loads $P_o\ P_1$, etc.

then $\delta_1 = \delta_o \cos \gamma_1$ $\quad\quad$ $\delta_2 = \delta_o \cos 2\gamma$, etc.

$$\frac{P_o^2}{\delta_o^3} = \frac{P_1^2}{\delta_1^3} = \frac{P_2^2}{\delta_2^3} = \frac{P^2_n}{\delta^3_n}$$

and therefore

$$P_1 = P_o \cos^{3/2} \gamma$$
$$P_2 = P_o \cos^{3/2} \gamma$$

Equating this gives

$$P = P_o\ (1 - 2 \cos^{5/2} \gamma - 2 \cos^{5/2} 2\gamma \ldots . 2 \cos^{5/2} n\gamma)\ [10]$$

From which calculation we have for instance for

$$\begin{array}{rccc}
z = & 10 & 15 & 20 \\
\gamma = & 36^\circ & 24^\circ & 18^\circ \\
\dfrac{P}{P_0}\begin{cases} = \\ = \end{cases} & \begin{array}{c} 2.28 \\ \dfrac{z}{4.38} \end{array} & \begin{array}{c} 3.44 \\ \dfrac{z}{4.36} \end{array} & \begin{array}{c} 4.58 \\ \dfrac{z}{4.37} \end{array}
\end{array}$$

$$P_0 + 2P_1 + \ldots . + 2\,P_n = 1.23\,P \quad 1.22\,P \quad 1.21\,P$$

89 The sum of the individual loads is almost invariable and the values also of $\frac{P}{P_0}$ are almost exactly equal to $\frac{z}{4.37}$.

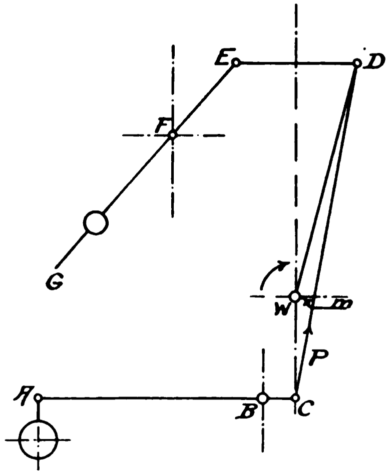


FIG. 19. DIAGRAM OF FRICTION SCALE

Therefore for

$$z = 10 \text{ to } 20$$

the largest load per ball is

$$P_0 = \frac{4.37\,P}{z}$$

90 Actually the assumptions that before loading the balls move without play in the races and that the races do not deflect under load, are not responded to so that the highest load on one ball will be greater and the sum of all individual loads smaller than the calculated values.

If we take for

$$z = 10 \text{ to } 20$$

$$P_0 = \frac{5\,P}{z} \qquad [11]$$

and

$$P_0 + 2\,P_1 + \ldots .2P_n = 1.2\,P \qquad [12]$$

then we get for

$$z = 10 \quad 15 \quad 20$$

$$P_0 = \frac{P}{2} \quad \frac{P}{3} \quad \frac{P}{4}$$

(P = bearing load)

Experiments With Ball Bearings

THE FRICTION SCALE OF THE CENTRAL LABORATORY

91 The scale was to permit the determination of the friction moment under loads up to 5000 kg. and any desirable rotative speed. Its scheme is illustrated by Fig. 19.

92 The beam $A\ B\ C$ of unequal levers carries the loading weight at the end A of its long lever arm. The strut $C\ D$ is supported at the end of the short lever arm E and transmits the load to the bearing through the suspension rods $W\ D$. The bearing surrounds a shaft that is journaled on either side in blocks and that may be rotated in opposite direction by suitable means.

93 So long as force P at C acts in the direction of connecting line $C\ D$, then with the shaft rotating in the direction of the arrow, the rod will deviate sidewise in the indicated direction and the friction moment of the bearing be Pm, being equal to the distance of force P from axis W. Considering the friction moment as the product of an ideal friction $\mu_i\,P$ and r its distance from the shaft axis, then, to get equality of moments,

$$\mu_i\,Pr = Pm$$
$$\mu_i\,r = m \qquad [13]$$

Since r has a definite value for every bearing μ_i is proportional to m. The deviation of the rod is therefore proportional to the ideal friction coefficient of the bearing.

94 In order not to sensibly change the direction $C\ D$ of the force P by friction at the supports, the strut is carried on hardened steel knife edges.

95 It must be taken into consideration that the weights of the strut $C\ D$, suspension rods $W\ D$ and the bearing act as rotating forces. To equalize their moments a second swing $E\ F\ G$ of smaller dimensions is employed, whose upward arm is connected to $C\ D$ by a short link $E\ D$ and whose downward arm $F\ G$ carries the balance weight. If $F\ E$ is made small with relation to $C\ D$, a small balance weight

only is needed. Shaping *F G* as a pointer playing over a curved scale will permit a more open scale reading of the friction coefficient and therefore greater accuracy than reading directly from the deviation of the main swing *C D*.

96 To adjust the strut *C D* so that its axis is simultaneously vertical and in line with the shaft axis is rather difficult. The bal-

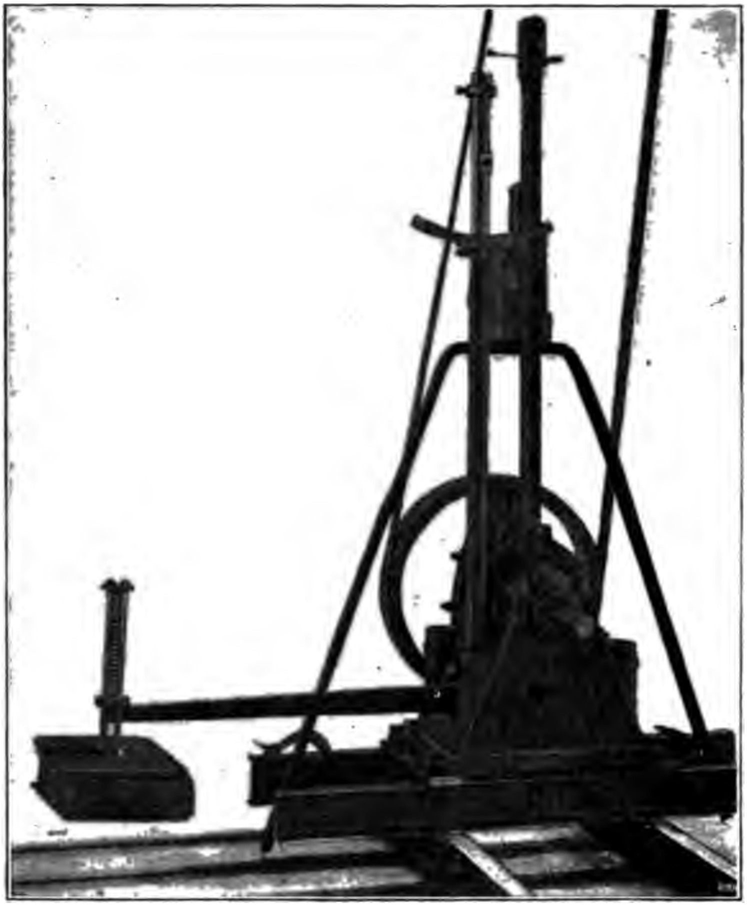


FIG. 20. THE FRICTION SCALE OF THE CENTRAL LABORATORY

ance weight permits the elimination of this necessity, provided the shaft is first rotated in one and then in the opposite direction and the readings of the pointer taken in both directions.

97 This proceeding gives reliable results, even when the scale is temporarily supported on a wooden foundation.

98 The balance swing and the connecting link are carried on knife edges so as to influence the sensitiveness of the scale as little as possible.

As Fig. 20 is built the main dimensions were made

$$A\ B = 1000 \text{ mm.}$$
$$C\ B = 50 \text{ mm.}$$
$$C\ D = 1560 \text{ mm.}$$
$$E\ F = 90 \text{ mm.}$$
$$F\ G = 360 \text{ mm.}$$

The total weight of strut, supporting rods, and bearing box was 74.70 kg. and that of the balance weight 0.3 kg.

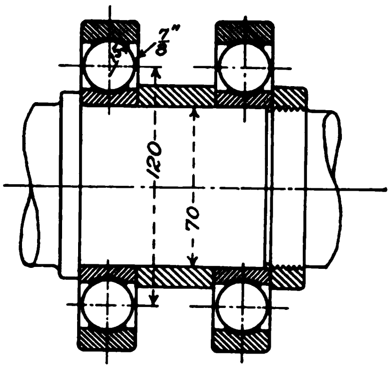


FIG. 21. TYPE OF BEARING TESTED

CARRYING OUT THE EXPERIMENTS

99 The suspension rods $W\ D$ carry a box into which the bearings may be inserted from the side.

100 An oil of moderate viscosity (Deutz motor oil) was used in such quantity that the bottom ball just dipped through it. Ball bearings may not be run without lubrication.

101 The oil temperature was determined by a thermometer inserted into the oil at one side of the bearing. This was sufficient since the temperature varied but slowly. So long as the balls do not lie in the oil, but are only moistened as may be required, the influence of the oil temperature on the bearing resistance is immaterial. It would probably be difficult to determine this influence, since the temperature will alter the shape of the bearings and races, which would also materially change the frictional conditions.

102 The ball bearing that was examined first made 65, 100, 130 190, 380, 780 and 1150 r. p. m. The lowest speed was taken first. The load was increased step by step from a small amount to the highest, and then again decreased in the same way. If, with similar loads, lower frictional values were observed with the decreasing load series, while the temperature did not differ materially it permitted the assumption that the bearing had not got down to good running conditions. The gradual reduction of the frictional values is very noticeable with bearings whose race surfaces were only roughly ground after hardening. *It is almost unnoticeable with races that have been so well finished that grinding scratches are not visible with the naked eye. This condition of the ball tracks is very important for the durability of races and balls.*

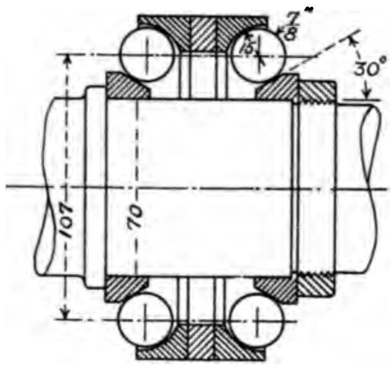


FIG. 22 TYPE OF BEARING TESTED

103 The same proceeding was followed with the same loads at all other speeds. If no disturbance arose before its conclusion the bearing was then examined. If neither the races nor balls indicated damage the investigation was continued, beginning again with the lowest speeds, but taking higher limiting values for the loads. When finally the appearance of the impressions indicated that the permissible load had been materially passed, a final endurance run at 780 r. p. m. with the greatest test load was made. By giving due consideration to the various observations the specific load k could be readily deduced.

104 The experience gained was naturally utilized for the later experiments, so that results were reached with less load and speed steps.

105 The friction scale gives directly only the ideal bearing friction coefficient. This was referred to the shaft diameter, so that the

results may be directly compared with the sliding friction of plain journals. We have therefore to consider the friction as equivalent to a resistance acting at the shaft circumference; the observation values are therefore the ratios of this resistance and of the bearing load. Since the radius of the shaft for all bearings tested was 3.5 cm., we find that with reference to the deviation m of the main swing of the friction scale, according to Equation 13

$$\mu_i = \frac{m}{3.5} \text{ with } m \text{ in cm.}$$

THE FRICTIONAL VALUES

106 In Fig. 21 the bearings were each made up of two ball races. This construction was found to be best for heavy loads. Four such bearings were therefore tested.[1] In order to determine the best steel different alloys and makes were used for each of these four bearings. The race running surfaces were grooves of a circular cross section with arcs having radii equal to two-thirds of the ball diameter. They were carefully finished and fairly free of grinding scratches.

107 The abundant observations indicate that:

a With loads from 1000 to 3000 kg. and all test velocities 65 to 780 r. p. m. as well as with oil temperatures of from 18 to 40 degrees cent. the friction coefficient differs but slightly. Its mean value is $\mu_i = 0.0015$.

b This friction coefficient increases noticeably only for loads below 1000 kg. With these low loads also it is almost independent of the speed.

108 Since the coefficient is independent of the speed within a wide speed range, the results can be given by the few values of the following table:

TABLE 4

R. P. M. =	65	385	780
Bearing load 380 kg. corresponding to $1.4\,d^{2*}$ $\mu_i =$	0.0033	0.0035	0.0037
Bearing load 850 kg. corresponding to $3.1\,d^2$ $\mu_i =$	0.0020	0.0021	0.0022
Bearing load 1100 kg. corresponding to $4.0\,d^2$ $\mu_i =$	0.0017	0.0018	0.0019
Bearing load 1580 kg. corresponding to $5.8\,d^2$ $\mu_i =$	0.0016	0.0016	0.0015
Bearing load 2050 kg. corresponding to $7.5\,d^2$ $\mu_i =$	0.0015	0.0015	0.0015
Bearing load 3000 kg. corresponding to $11.0\,d^2$ $\mu_i =$	0.0015	0.0013	0.0013
Bearing load 4900 kg. corresponding to $17.9\,d^2$ $\mu_i =$			0.0011

*d = ball diameter in eighths of an English inch and $1.4\,d^2$ = largest load per ball.

[1]Translator's Note: The use of several rows of balls is admissible only under conditions that permit an equalization of the total load among the several rows. This condition is but rarely fulfilled in practice, so that one row to a bearing and that heavy enough, must be considered the standard arrangement.

109 The merely moderate variations of the observations have been previously averaged. It may be assumed that with less careful workmanship or a too great flooding of the bearing with a heavy lubricant the speed will be of greater influence on the bearing resistance.

110 For loads from the permissible to half that value, that is to say, from 3000 to 1500 kg. μ_i varies between 0.0013 and 0.0017.

The coefficient f of rolling friction is to be derived from

$$\mu_i \, Pr = Sf \frac{D_o}{d}$$

in which S is the sum of all the individual ball loads and is, as has been previously shown, $= 1.2\ P$ with P representing the bearing load; it therefore holds true that

$$\mu_i \, r = 1.2 \, f \frac{D_o}{d}$$

and with

$$r = 3.5 \text{ and } \frac{D_o}{d} = 4.4$$

$$f = \frac{3.5}{1.2 \times 4.4} = \frac{2}{3}\mu_i$$

with μ_i =0.0013 to 0.0017 it follows that $f = 0.0009$ to 0.0011.

111 In Fig. 22 the journal was made up of two ball rows. It ran with 65, 130, 190, 385, 580, 780 r. p. m. and under loads from 380 to 3000 kg. The friction coefficients are almost 15 per cent greater than for the design of Fig. 21. As for the rest, the speed had similarly little influence as with Fig. 21.

112 The journal in Fig. 23, consisting of two ball rows ran only 380 and 780 r. p. m. and under loads from 380 to 1800 kg. An influence of the speed could not be definitely determined.

For 380 kg. load, it gave $\mu_i = 0.0051$.

For 850 to 1800, $\mu_i = 0.0033$ to 0.0037.

The temperature ranged between 30 and 45 degrees cent.

113 Under the highest load of 1800 kg. sliding and rolling frictions participate equally in the frictional work; with decreasing load the share of the sliding friction decreases while that of the rolling friction increases.

114 A heavy ball bearing, in order to replace a sliding journal of the best type, must have less frictional resistance than the journal in Fig. 23. This design is therefore not suitable for practical use.

115 In Fig. 24 the journal was also made up of two ball rows. At 380 and 780 r. p. m. and 1100 to 3500 kg. load it gave $\mu_i =$ 0.0052 to 0.0060. In an endurance test under 3500 kg. load at 780

revolutions per minute the temperature rose in three hours from 84 to 130 degrees cent. without change of the friction coefficient.

116 With 3500 kg. journal load the sliding frictional work is almost 3.5 and with 1800 kg. it is still twice as great as that with rolling friction.

117 The remarks concerning the practical value of the journal of Fig. 23 apply even more forcibly to that of Fig. 24.

118 Investigation covered two journals, as shown in Fig. 25. The first was made before the beginning of the tests. At that time there were no available data for the permissible loads and the frictional values. It was also the first examined.

119 Merely the circumstance that several of the ball tracks still plainly showed grinding scratches developed that such journals require some time to get down to uniform running conditions. The journal was observed for five weeks, during which time it ran daily

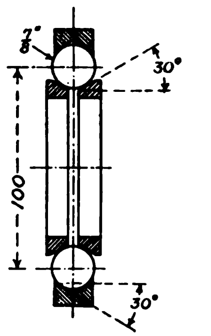


FIG. 23

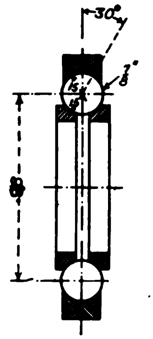


FIG. 24

TYPES OF BEARINGS TESTED

from two to nine hours. It developed that, as with my earlier experiments on cast iron worm gearing the state of uniformity, corresponding to a constant frictional value, was reached earliest for a given load by allowing the bearing to run for some time under a materially higher load. With our test procedure with step by step load increase and decrease this state of uniformity was soon reached for the lighter loads; it required more time for the heavier loads.

120 The investigation was finally terminated at 580 revolutions per minute and 4200 kg. load because two races showed damage. The observation at 780 and 1150 revolutions per minute therefore extend up to a load of only 2050 kg.

121 It would seem that since with the higher loads that were reached at each speed the journal had not yet got quite down to uniform running conditions, the reduction of the friction coefficient with

increasing speeds as given in the following table should be partly ascribed to this condition.

122 The friction coefficient may therefore, for the slower speeds and higher loads, be somewhat smaller than that given. The following table gives the values derived from the readings:

R. P. M. =		6	100	190	380	580	780	1150
P = 380 kg.	μ_i =	0.0095	0.0095	0.0093	0.0088	0.0085		0.0074
P = 1100 kg.	μ_i =	0.0065	0.0062	0.0058	0.0053	0.0050	0.0049	0.0047
P = 1800 to 4200 kg.	μ_i =	0.0055	0.0054	0.0050	0.0043	0.0041	0.0041	0.0040

P = 1800 to 2500 kg.

123 With 1800 kg. journal load the work of sliding friction is one-third to one-quarter of the total frictional work. The design is therefore not bad so far as the frictional conditions are concerned. But the balls of the test journal are too small. To get acceptable frictional values, balls of $\frac{7}{8}$ inch diameter should have been selected.

124 The races of the second journal had well finished and polished ball tracks. It was made of different steel and was tested in order to give data as to the suitability of that. The load was rapidly raised beyond the permissible amount to 4200 kg. Under the heavy overload an outer race broke, before the heavy load got down to uniform running. The frictional values observed were therefore all slightly higher than those cited.

PERMISSIBLE SPECIFIC LOADS k

125 Balls and races in Fig. 21 acted perfectly at loads under 3000 kg. and all trial speeds up to 780 revolutions per minute. A few hours of endurance run with 4900 kg. at 780 revolutions per minute plainly showed slight variations in the hardness of the ball tracks. The softer places showed deeper impressions and looked darker than their surroundings. Under continued running, flat holes are formed at the soft spots, with edges more or less sharply defined in accordance with the peculiarities of the material.

126 Of the four journals, whose races were made of different steel, two showed up similarly. The races of the other two proved uniformly hard and withstood the test. But whereas with one the ball tracks were just barely noticeable, they were decidedly defined with the other.

127 These experiences indicate that 4900 kg. is an inadmissibly high load.

Basing 3000 kg. as a permissible load on these observations, gives k by calculation as below.

The load per ball row is 1500 kg. and with 14 balls the greatest load per ball is, according to Equation 11,

$$1500\tfrac{5}{14} = 536 \text{ kg.}$$

with

$$d = \tfrac{7}{8} \text{ inch}: k\,7^2 = 536$$

approximately,

$$k = 11$$

Taking $k = 10$ gives for a ball supported in a groove with a radius of curvature $= \frac{2}{3}\,d$

$$P = 10\,d^2 \text{ (}d\text{ in eighths inch English)}$$
$$P = 100\,d^2 \text{ (}d\text{ in cm.)}$$

128 The journals of Fig. 25 were also loaded up to 4200 kg., but were damaged under this load. The ball track became sharply defined under an even smaller load. Even with uniformly hard ball races, this journal will hardly carry reliably more than 1800 kg. The outer ball races are the more heavily loaded; the average load on each of the central tracks is the 0.29, that on each of the side tracks the 0.23 part of the total journal load.

129 For the permissible load of 1800 kg. the corresponding amounts are 522 kg. and 414 kg. The central tracks each have 22 balls, so that the greatest load per ball approximates

$$522\,\frac{5}{22} = 120 \text{ kg.}$$

For the side tracks, each with 20 balls, the greatest load per ball figures out

$$414\,\frac{5}{20} = 104 \text{ kg.}$$

so that

$$k = \frac{120}{5^2} = 4.8$$

130 Note also that the relative movement between balls and outer races, where the greatest loads occur, is almost exclusively a rolling one. At the ball tracks of the central inner race, where the balls also slide and are, to judge from their appearance, amply loaded at 1800 kg. journal load, the greatest load per ball approximates 90 kg.

For these tracks we get

$$k = \frac{90}{5^2} = 3.6$$

For flat, conical and cylindrical track surfaces we have

$$P = 3\ d^2 \text{ to } 5\ d^2 \quad (d \text{ in } \tfrac{1}{8} \text{ inch English})$$
$$P = 30\ d^2 \text{ to } 50\ d^2 \quad (d \text{ in cm.})$$

131 The smaller values are to be used where there is simultaneous rolling and sliding friction at the points of principal load, the larger values when there is only rolling friction. The load $5\ d^2$ is already relatively high and is certainly nearer to the ultimate load at which inequalities of the material become disagreeably apparent than the load $10\ d^2$ given for the grooved cross section.

132 On reconsidering the results of the friction and load investigations we recognize that only the races illustrated in Fig. 21 are fully satisfactory for bearing journals. The use of such races gives us entirely practical dimensions for journal loads of 6000 and 10,000 kg. and frictional values responding to the most critical demands.

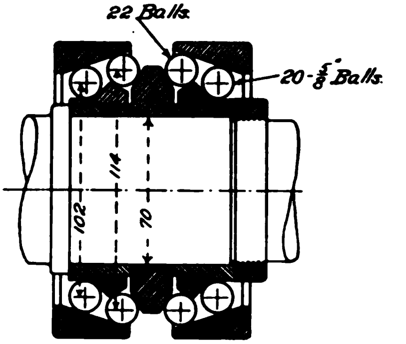


FIG. 25 TYPE OF BEARING TESTED

133 The German Small Arms and Ammunition Factories of Berlin have, for the past year, been proportioning ball bearings in accordance with this report.

134 There have been made there and carefully observed in practice ball bearings of widely differing designs, and it has been uniformly found that the statements here made hold good.

135 The investigations here reported were concluded in March, 1899. In continuation and concurrently with the German Small Arms and Ammunition Factories, Berlin, work looking to the further improvement of the larger steel balls and races has been carried on. It has been attended with success and resulted in the manufacture of balls and races that may be more highly loaded than those with which the results reported were reached. In examining such races a journal such as Fig. 21, but with only one ball row was for a long

period submitted to a load of 4900 kg. at 780 revolutions per minute, this being the highest within the capacity of the friction weighing scale. Under this load, which is double the previous one, the ball tracks were barely marked and no difference in the hardness developed According to experience so far, the permissible loads of balls and races may be taken 1.5 times as great as previously reported.

136 These frequent examinations have also shown that the ball bearings are very uniform as to their friction. The greater or lesser viscosity of the lubricant influences the friction but slightly. In many situations they possess various advantages over sliding journals.

137 The necessity for getting down to a uniform bearing which not infrequently seriously handicaps sliding journals, is eliminated with well made ball bearings. They are short, and even for high speeds and loads no larger than for low speeds, and are suitable under conditions where sliding journals must be made undesirably long to avoid seizing and to conduct away the heat generated. Dust and other uncleanliness in the oil, for instance, not perfectly removed cores, can more easily be kept off of the supporting surfaces and are less harmful than with sliding bearings.[1]

138 The reliability of ball bearings is the quality most generally doubted. After my first experience with them, I had no great hopes in this direction, but after observations that I have since made of properly proportioned and carefully made ball bearings, I incline to the decision that it is owing to their very reliability that they respond to extreme demands and that therefore their use is advisable even where sliding journals wear rapidly.

139 These good qualities are, however, found only in bearings whose balls and races are made with sufficient accuracy and that respond, as to uniformity, hardness and toughness, to certain requirements, the compliance with which will probably always remain the province of a very few specializing concerns.[2]

[1]Translator's Note: This must not be taken as a license to fill a ball bearing with dirt, grit, etc., which must necessarily reduce the surface and so destroy one of the very great advantages of the ball bearings, *i. e.*, its practical immunity from wear during the full lifetime of the mechanism it carries. Single row ball bearings permit the shaft to oscillate slightly, so that slight deflections of the shaft or slight errors in fitting do not appreciably affect their good action.

[2]See "Zeitschrift des Vereins deutscher Ingenieure, Vol. of 1897, p. 968, and Vol. 1898, p. 1157.

DISCUSSION

Mr. Thomas J. Fay While little remains to be said about ball bearings and their uses, in view of Mr. Hess' most excellent résumé, the writer wishes to emphasize one or two points.

2 It is well understood that it is essential not only to employ perfected radial types of ball bearings, but good materials; and this question of materials needs more light because among engineers there is a diversity of opinion with regard to it.

3 It is believed that the success of the bearings advocated by Mr. Hess is in a large measure due to the fine quality of materials used, as well as to their design and construction.

4 It is quite apparent that steel made by a process that requires no burning out of impurities is more likely to be of high quality than if it is produced from cheap raw materials which require such treatment. The chemical composition of steel does not alone indicate its quality. Identical chemical compositions may be followed by marked differences in results. In order to secure the same results the composition must not only be the same but the steel must be produced from identical raw materials, by one process, at the hands of men doing that class of work and knowing the details of the process.

5 The life of a ball bearing is dependent upon numerous considerations of design and upon the sizes used and the mode of application; but tests now under way in the establishment represented by the writer indicate that trouble can be expected well within 20,000 car miles from all but the finest products, even when the load is one-half the usual catalogue ratings. Of course plain bearings would fail long before this under the same load conditions. But the very best makes of ball bearings using the most appropriate grades of steel should survive 50,000 car miles.

6 Trolius, in "Notes on the Chemistry of Iron," second edition, p. 129, arrived at conclusions bearing upon this subject, that the writer has been able very accurately to verify. He said among other things: "There is something in steel for which we cannot account; 'body' it is called in Sheffield and Sweden * * * ." Again, "It is quite possible that the presence of minute amounts of elements that are generally not included in what is termed a complete analysis of steel, may cause some of the wide differences in physical properties which are sometimes observed in otherwise similar steels." And again, "The cast steel (which is a continental designation for crucible steel), made from the best Swedish steel iron has more 'body' than other cast steel; moreover, the products from this soft steel show an endurance

in service, a 'body' that can rarely be attained by steel made from other materials and doctored."

7 In further illustration of this matter Trolius goes on to say: "The following analysis shows the composition of soft Bessemer steel made from the Swedish steel iron ores and a steel made from cheaper ores.

	Swedish ore	Cheaper ore
Carbon	0.10 to 0.15	0.11
Silicon	0.01	0.01
Sulphur	0.01	0.04
Phosphorus	0.027	0.065
Manganese	0.14	0.51

8 "The Swedish steel shows a decidedly better chemical composition, but when the composition happens to be alike, or nearly so, the 'body' will assert itself in favor of the Swedish steel."

9 The writer holds that modern methods of investigation, including "vibratory tests" micro-photographs and other methods adequately establish the fact that but minute differences in composition influence the results to a marked degree, in that the "eutectic" is diverted out of its condition of natural selection, excepting in the products free of these minute quantities.

10 With a view to being able to afford accurate advice on this subject, the writer, in association with Mr. J. M. Ellsworth, has now under way a full set of investigations of ball bearings, not only of the materials of construction, but the life as well, and with the hope of throwing some light on the subject, offers the chemical determinations as follows:

11 Number 86, inner raceway of a Hess-Bright D. W. F. ball bearing, made in Germany. Chemical composition: Carbon, total, 0.983; combined, 0.983; Cr 1.24; V none; Mn 0.43; S. 0.034; Ni none; W none; Si 0.197; P 0.015; M none; Ti none. This raceway was a part of the bearing of which test record No. 87 relates. Obviously the two races were not from the same "heat" of metal unless segregation is a factor. At all events the sole alloying element was chromium.

12 Number 87, outer raceway of a Hess-Bright D. W. F. ball bearing, made in Germany. Chemical composition: Carbon, total, 0.941; combined, 0.941; Cr 1.21; V none; Mn 0.15; S 0.039; Ni none; W none; Si 0.202; P 0.022; M none; Ti none. The bearing was disrupted by side pressure, and showed a decided elongation before fracture. The raceway was file-hard but was not cemented. It was definitely determined that this product held chromium as the sole

alloying element. Obviously this product would be rendered file-hard by quenching.

13 Number 88, outer raceway of the ball bearing from *Société Française des Roulements.* Chemical composition: Carbon, total, 0.893; combined, 0.893; Cr 1.60; V none; Mn 0.30; Ni none; W none; Si 0.188; P 0.019.

14 Number 89, inner raceway of the ball bearing from *Société Française des Roulements.* Chemical composition: Carbon, total, 0.80; combined, 0.80; Cr 1.58; V none; Mn 0.19 S 0.029; Ni none; W none; Si 0.197; P *0.022.*

15 Number 90, taken from a ball bearing purchased from makers for test purposes. Chemical composition: Carbon, total, 1.165; combined, 1.165; Cr none; V none; Mn 0.18 S 0.016; Ni none; W none; Si *0.027*; P *0.027.* This shows the balls were of "tool steel" of the carbon steel series, since no alloying element was found.

THE AUTHOR The discussion emphasizes the need of high grade material for balls and races that may be heartily subscribed to. It is true that with inadequate material, correct design and good workmanship are of little avail.

2 Mr. Fay is correct in his statement that case-hardened (cemented) material will not answer. A steel that will harden throughout and be practically uniformly hard and tough is a *sine qua non* where durability and long life are wanted.

3 Several chemical analytical investigations of ball bearing materials are offered by Mr. Fay. I am inclined to doubt the accuracy of the chemist employed—certainly the analysis given does not respond to any that I am familiar with as employed in D. W. F. ball bearings.

4 The discussion refers to the usual catalogue ratings of ball bearings. In my practice the catalogue rating is the safe steady load at steady speed. It must be manifest that the carrying capacity under sudden variations of load or of speed, that is under shock, is less. In the body of my paper general rules for size selection have been given for the various chief automobile elements.

5 Since in a perfectly designed ball bearing, that is properly mounted to be free of grit, rust and acid, wear is not a factor affecting its life, there remains only the molecular change, due to repeated stress to curtail its existence. In my opinion and practice a ball bearing that does not outlast the machine (automobile or other mechanism) on which it is used, is either defective in itself or shows proof of an improper type and size selection.

6 Changes in design and fashion of automobiles are such as to make the amertization life certainly not over five years, so that their bearings should not require renewal inside of that time. Few cars will average 50 miles per day for 250 days per year or a total of 62,500 miles. I have in my possession bearings taken from a heavy touring car that has been roughly used in racing and hard driving; these, with a known record of 65,000 miles, show no evidence of deterioration. Other records on standard passenger steam railways are over 200,000 miles with no visible effect on the bearings.

MONTHLY MEETINGS

HELD IN NEW YORK ON OCTOBER 8,
AND NOVEMBER 12, 1907

MONTHLY MEETINGS

The October Meeting

The October meeting was held on Tuesday evening, October 8, when Professor John Price Jackson of State College, Pa., gave an address on "College and Apprentice Training." It treated of the relation of the student engineering course in the industries to the college technical course. There was a great deal of valuable discussion. Among those who took part were Prof. Dugald C. Jackson of the Massachusetts Institute of Technology and President of the Society for the Promotion of Engineering Education; Dr. Henry S. Pritchett, President of the Carnegie Foundation for the Advancement of Teaching and President of the Society for the Promotion of Industrial Education; Dr. Arthur A. Hammerschlag, Director of the Carnegie Institute of Pittsburg; Dr. C. F. Park, Director of the Lowell Institute; Mr. C. W. Cross in charge of the Apprentice Courses in the New York Central Lines; Dr. Fred W. Taylor, Past-President of the Society; the Secretary, and others. Professor Jackson's address is published in this volume.

BUSINESS MEETING

Previous to the professional session on October 8 a specially called business meeting was held to ratify the action of the officers in entering into an agreement with the Mechanical Engineers Library Association to merge the Mechanical Engineers Library Association and The American Society of Mechanical Engineers into one body to be known as The American Society of Mechanical Engineers.

Proxies had been previously sent out in the names of Prof. F. R. Hutton, or Mr. C. W. Hunt, or Mr. Henry R. Towne, and these together with the ballot vote at the meeting, formally ratified the action which had been taken. The meeting further prayed that the Supreme Court be petitioned to grant this merger.

On October 15 in the rooms of the Society a similar meeting of the Fellows of the Mechanical Engineers Library Association was held which ratified the action of their officers.

THE NOVEMBER MEETING

Mr. Charles R. Pratt addressed the Society at the November meeting on Tuesday evening, November 12, the subject being "A High Speed Elevator."

Much valuable information in regard to the construction and operation of elevators was brought out in the discussion in which engineers and architects from New York, Philadelphia and Chicago participated. The paper is published in this volume.

No. 1160

COLLEGE AND APPRENTICE TRAINING

THE RELATION OF THE STUDENT ENGINEERING COURSES IN THE INDUSTRIES TO THE COLLEGE TECHNICAL COURSES

BY PROF. JOHN PRICE JACKSON, STATE COLLEGE, PA.
Member of the Society

Near the year 1880 a new spirit in collegiate education had begun to grow vigorously. A few institutions previous to that time had been established in accord with this spirit which maintains that a college should prepare a man to do his duty successfully in any of the various pursuits of life, and not only in what are termed the "learned professions."

THE MORRILL LAND GRANT ACT—ITS TENDENCY

2 One great impulsion toward a practical and useful form of education for the bulk of the middle classes of the people was undoubtedly the now well known Morrill Land Grant Act passed by Congress in 1862 providing for the establishment of State institutions, the primary object of which was to be, "without excluding other scientific and classical studies, and including military tactics, to teach such branches of learning as are related to agriculture and the mechanic arts, in such manner as the Legislature of the State may prescribe, in *order to promote the liberal and practical education of the industrial classes in the several pursuits and professions of life.*"

3 The wisdom of this act was not generally appreciated for twenty or more years after its passage, and even at the present time, its full fruitage is only beginning to be harvested. Under it colleges were established in nearly all the States of the Union receiving partial support and direction by the National Government, having as a fundamental constitution the passage of the Act quoted above. Even as

Presented at the regular Monthly Meeting, October 8, 1907 of The American Society of Mechanical Engineers and forming part of Volume 29 of the Transactions.

late as 1880 and 1890 these institutions were considered more or less in the light of manual trade schools by a large element of the educated classes. They have thriven so successfully, however, during the last two decades that not only did they take position as high types of educational institutions doing a magnificent service, but the principles which actuated them proved so vital that all of the best institutions of higher learning in the country have been materially molded by the effect they have produced; indeed, today the first and primary object of all well organized colleges is to prepare men for a life of usefulness rather than for the purpose of giving them culture and polish.

4 This attitude, or spirit, which has been thus induced, is filtering down into the lower branches of education as evidenced in the manual training schools, and many of the high school courses, which are eminently fitted to prepare young men and women to perform efficient service in maintaining our present complex civilization. The same spirit will reach still further and will quicken the grammar and even the primary grades of education. Though the "three R's" will of course remain the essential basis of all primary education, the new motif will weave around and through them a training in the observation and understanding of simple natural phenomena, which will do much to increase the usefulness and happiness of the great masses of the American people.

THE EARLY COLLEGE MEN AND THE INDUSTRIES

5 The earlier institutions, from about 1850 to 1880, which dealt with higher technical instruction, confined their work largely to what is called civil engineering, and for that reason it will be found that the civil engineering staffs of the railroads of the country are, to quite a large extent, and have been for many years, composed of college men, but the manufacturing and similar industries of the country are even yet extensively officered by men who have had to obtain their necessary training through individual study. When the use of electricity became an important factor in our daily life about twenty-five years ago, the need for brains trained in the mathematical and physical principles underlying the use of electrical phenomena became so great that the colleges prepared to do so were forced to furnish adequate courses in these subjects. It will be found, therefore, that the electrical industries are very largely controlled by college bred men especially prepared for their work. In the mechanical industries—which require fully as much preparation—

and in the mining, metallurgical, marine, and steam industries, the movement has been much slower, but at the present day it is assuming a rapid growth. Probably of all these professions that of mining has lagged behind most in demanding highly educated officers.

6 The relation between the colleges and the industries during the period from 1880 to 1890 was critical in regard to technical education in this country. At that time, when a young man was graduated from a technical college course he was, to all visible evidence, less desired and useful to the industries than if he had gone into the shop and taken an ordinary apprenticeship course for four years. As a matter of fact, in order to get a start at all, such a young man by necessity was compelled, except in unusual cases, to apply for work without permitting it to become known that he was college bred, otherwise he was foredoomed to failure. If he succeeded in obtaining a position, but afterward it became known that he was a college graduate, he was placed under a serious handicap of prejudice. On the other hand, if his educational advantages did not become known, the chances were strong that he would forge rapidly ahead of his fellows in his work and quickly take a position of responsibility and control. At that time the need of a college bred man was not so insistent as at present, but even then machinery was growing more complex and the call for power units of increased size was becoming urgent, both on account of higher speed of travel—railway and steamboat—and on account of the larger production machines which the industries were rapidly adopting; thus, even then the need of a greater number of well trained brains was becoming imperative. At that time the educational preparation in the sciences was to a large extent in an experimental stage, but a good foundation in mathematical reasoning and the fundamental principles of physics, dealing with dynamic and static forces, were being taught in a number of institutions and the men who were being graduated were not badly prepared to step into the industries—at the bottom of the ladder. One of the difficulties experienced by employers at that time was possibly due to a lack of appreciation on the part of the young men themselves that notwithstanding their four years in college it would be necessary to start at the bottom and learn from its incipiency the business they were about to enter.

THE CONNECTING LINK

7 Early in the last decade when our industries were rapidly growing in complexity, this call for trained men became so urgent that it

was necessary for the managers of the industries to take measures to supply the need. A survey of the field showed that the young men who were being graduated from the scientific colleges, then in comparatively small numbers, were not fitted to take positions of responsibility, and it seemed at that time doubtful whether such men had or could obtain the practical cast of mind which is essential to technical work. Certain far sighted managers connected with the Westinghouse, General Electric, and Western Electric Companies, and other industrial concerns had been employing some of these men and were putting them through a more or less rigorous course of preliminary training with the idea of preparing them for usefulness to their companies.

8 An early step was described in a circular letter written in the 90's by the shop superintendent of one of the companies and sent to a number of the leading engineering colleges of the country. In this letter, the writer in essence stated that his company had decided to employ a number of newly graduated men each year at a low rate of compensation and would teach them the details of the business during a course of about two years. It was stated in the letter that the men who were appointed were to be considered as receiving scholarships, and it was hoped that the colleges would hold forth to their classes these positions as incentives to a high grade of work. Appointments were to be made strictly on the basis of the records of the young men. As stated previously, other companies were also taking this stand, in most cases in a less formal way. For eight or ten years such *student engineering courses* in the industries have been springing up in large numbers all over the country.

GROWTH OF THE MOVEMENT

9 It is the link offered between the technical colleges and the industries by these student courses in the shops and power plants with which this paper has to deal. This link lies in the mind of the writer as one of the greatest advances in useful education which the world has ever seen accomplished in the same space of time. In the old days the boy who graduated from a literary or classical college, and who found himself unfitted for the learned professions, was apt to become a pauper and a burden upon the community; and, as already said, even the technical graduate had great difficulty at first in making himself useful and valuable. Today, on account of this new type of post graduate industrial education, every young man who has received his bachelor's degree, and who has a fair modicum of brains

and common sense, has fields innumerable open to him which lead, possibly by slow steps, but surely, to positions of responsibility and usefulness which carry with them in the end excellent rewards to men who give energetic, and studious service.

10 From about 1872, ten years after the Morrill Act was passed, until 1887 the technical courses in the colleges were being developed. The next ten years was a period during which the industries and the colleges were endeavoring to adjust some means whereby a very distinct and apparently insurmountable gap between the work of the two could be bridged; and from about 1897 to 1907 may be considered a period during which the industrial companies were developing the student engineering courses and the colleges were modifying their courses so as to meet this development. The dates given approximately indicate quite indistinct time divisions.

IDEALS IN STUDENT ENGINEER COURSES

11 The student engineer courses of the industries, where they have been fairly well established, at the present day extend usually over two years and enable the young graduate actually to perform the processes with his brain and hand on each important operation in the establishment, whether it be the factory or power plant. Possibly the quotation of statements from men directly in charge of the young graduates would at this point aid in making clear the ideals which have underlain the development of the work to the present time.

12 The quotations I have selected are from a file of letters of Mr. A. L. Rohrer, General Electric Company, Mr. Chas. E. Downton, Westinghouse Electric and Manufacturing Company, Mr. A. T. Bruegal, Fairbanks Morse and Company, N. C. Bassett, Allis Chalmers Company, C. E. Scribner, Western Electric Company, J. M. Gilmore, formerly of the Stanley Electric Company, The Union Switch and Signal Company, Baldwin Locomotive Works, The Pennsylvania Railroad Company, and others.

13 Portions of one statement are as follows:

Very early in the history of the company it was found desirable, or rather necessary, to train its own men and at first they selected bright, intelligent young men, who, in many cases, had had some mechanical experience. Later on, when colleges began to shape their work so as to include more and more electrical work and, finally, to put all this into a regular course of electrical engineering, the men were put through a system of practical training. This work finally led up to what was then called a student's course, because practically all the men who entered had either been students or had graduated at some one of the technical schools or colleges. At one time this work was supervised by a man who had great confidence in the English scheme of practical training whereby the men paid a certain stipulated amount each year for the privilege instead of receiving a salary. It turned out to be more or less of a failure for the reason that many a bright man was debarred from entering the course on account of the fact that he had either paid his way through college or could not afford to borrow money to make payment to the company.

It was then changed and men were employed regularly for work in the testing department. At one time they began at the rate of 8 cents an hour. After awhile they were paid 10 cents when entering, and later 12½ cents and 15 cents, their rate of pay being advanced from time to time as their services warranted.

During all this period great stress was laid upon the work in the testing department. It was believed that these men were best fitted for testing work as it was following along the general line of their laboratory work in college, but opportunities were offered at different times for certain of the men who had shown special ability to get some training in the mechanical departments. At one time the men who were selected for positions in our engineering departments were given several months training in our shops, then sent to the drafting department for several months, and then into the office of one of the designing engineers. We are now giving all the men who enter the testing department a short period of training in our shops as soon as they enter our employ; that is, the work which they do first is in the mechanical departments as preliminary to the work in the testing department. It is believed that from ten to twelve weeks can be spent to good advantage as it enables them to obtain an insight as to how the apparatus is put together. The principal part of their work, therefore, while in the shops is on assembling work.

We have arranged a schedule which we follow as closely as conditions of production will allow, but the men all understand that if necessary they must remain in one section much longer than the schedule calls for. If, however, the men are transferred in accordance with the schedule about twenty to twenty-two months are required to get all the training. We really put ourselves to considerable inconvenience in transferring these men, because about the time they become proficient in one class of work they are transferred to another section, but we feel that in the end we are repaid for so doing.

We do not ask them to enter into any contract to remain with the company a specified time. They are treated in a broadgage way, and all we ask is that they spend sufficient time with us to become familiar with all the apparatus and to be really good representatives of the men who have been through the testing department. We never stand in the way of a young man who has an opportunity for a good position outside; in fact, we are just as anxious to have good men with our customers as we are to retain them in our employ. There is nothing philanthropic about this as there are in the employ of a large percentage of all the electric railway and electric lighting companies men, who at one time or another have been in our testing department. I think I am safe in saying that they are all good friends of the company and realize that the time spent here has been of great advantage to them.

14 Another man describes the work in the student engineer course under his charge as follows:

Only a few years have passed since the college man was looked upon askance by the then self made practical engineer, and the young man about to start in the profession had great difficulty in gaining recognition from any one. No one of that day wanted a young man who had "received his knowledge from books."

Another reason not expressed, but nevertheless felt, and proved by careers of prominent engineers of today and the great demand for technically trained men, was that the theoretical man with practical experience would eventually become an important factor in the organization and, hence, a keen rival.

Industrial enterprises, where results mean dividends, have for some time recognized and taken advantage of the opportunity to build up the directing force with men of this caliber.

The company has organized its engineering apprenticeship system for the sole purpose of furnishing recruits to departments having vacancies or where there is need for additional help.

Seventy-five per cent of the men will be given positions of responsibility in the company's service or be placed by the company in electric lighting or railway work, which is quite to the company's advantage, since the young men will be in the field with a thorough knowledge of the products manufactured here.

I believe it is quite generally admitted by heads of schools of engineering that the young man leaving college is rarely of, if any, immediate service to the profession. This, we know, has been our experience.

The apprenticeship course not only gives him an opportunity to gather information relative to engineering and factory methods, but it places him in a position to be observed by others—a sizing up process as it were—which gives us possession of information regarding his personal qualities and characteristics.

Our course is divided into three sections: *a* shop or actual manufacture, *b* engineering or designing, etc., *c* testing or operating. This, we have found, gives the broadest experience and a sure method for the selection of men for specific lines of work.

The course in the shops is scheduled by departments, no attempt being made to specify any particular work. This is left entirely with the foreman in charge, who will assign work in a way to accomplish the best results. Any one showing superiority in the use of tools will be given a task of value proportionate to his skill. A great portion of the information gathered is obtained through observation.

Until quite recently no concentrated effort was made to develop men for any department other than engineering and erecting. Now we are including manufacturing, selling, correspondence, and in fact every department within the organization.

15 Another employer writes:

The students will be subject to the conditions of the other workmen where they happen to be placed: they must accept the same hours, regulations, piece-work prices, overtime allowances, etc. They will have, however, one assurance which other workmen do not have, *viz.*, that they will not be laid off on account of ordinary periods of slack work, and in return for this consideration they will be expected not to withdraw until they have finished the course.

At the completion of the course, the obligation on both sides will be at an end and the men must be prepared to look out for themselves, because the company will further employ only such of the graduates as it may need as engineers and assistants in its various departments.

The following will be the approximate distribution of a man's time, working in the shop, the first year.

Generator and motor assembly	4 months
Switchboard assembly	2 months
Transformer assembly	2 months
Winding and insulation	2 months
Annealing	1 month
Inspection	1 month

The second year will be spent in the testing department.

Generator testing	4 months
Motor testing	2 months
Transformer testing	2 months
Instrument testing	2 months
Arc lamp testing	2 months

The last six months' time will be spent either in the outside construction or ommercial or drafting department.

It must be understood that the company does not bind itself strictly to these schedules. Occasion may sometimes require that a man's time in one department be shortened or lengthened: and a student may omit some departments entirely, when his services are wanted in more advanced work: but the student's own wishes will be consulted as far as possible.

Applicants must be graduates in electrical or mechanical engineering from institutions of good standing. They must secure a good recommendation from the man under whom they have done their practical work in electricity at school and a good reference from a previous employer if possible.

Applicants must answer satisfactorily questions as to age, descent, physique strong or indifferent, school or college course, record in studies, record in laboratory, whether it is the intention to complete the student's course as outlined, what experience he has had in electrical work outside of school, how soon he could begin work in the department named, what is the latest date that would suit the applicant.

16 Some of the items in the circular of another company are:

The applicant must be a graduate of a school of technology. Students shall serve for an equivalent of two years of 2750 working hours each.

The company does not wish all the students in each year's class to start in at the same time, but prefers rather to spread them out over a space of several months, from June to October. In making application for the students' course, applicants will therefore say when they prefer to begin work. Their preferences will be followed as far as possible, but the company reserves the right to fix the dates for beginning work.

At the end of the entire term of service, for the faithful performance of his duties throughout the course, each student will be paid a bonus, but this bonus will be reduced *pro rata* for students who may be permitted to shorten their course and who may then be taken into the company's regular service. No bonus will be paid to students who leave the company's service before the end of the course, or who may be discharged for cause.

The company reserves the right to discharge any student at any time for misbehavior, unfaithfulness, disobedience of orders, improper conduct or continual failure to comply with the rules of the company.

During the first quarter year, or 685 hours, students will be considered as on trial and may be discharged during or at the end of this period if the company should be of the opinion that the student is not qualified to continue the course, or for personal or other reasons is not desirable as an employee or as an associate of other students.

Students shall be subject to all shop and office rules.

After having satisfactorily completed his full term, or such shorter term as the company may decide upon in any individual case, the student will be given a certificate certifying to the same, which will be signed by the superintendents of the works where he has been employed, and the heads of other departments in which he has worked.

17 It is seen from the letters and the descriptions of the courses that they are laid out by practical men for the purpose of training the young graduates for positions of responsibility. In all cases, so far as the author has observed, the student is passed from department to department until he has fairly mastered the fundamental details of the entire business. In most cases, in addition to shop work, erecting, etc., the man also must pass through courses in the designing rooms and the commercial departments. Though schedules are arranged they are not always followed out exactly, as in some cases a young man shows proficiency in certain lines of work, while in others he needs extra time, though it is to be presumed that the time allowance for each division of the course is proportioned to meet the requirements of the average student. To all appearances the schedules made out for the men are based purely upon what will form the best training, without special regard to what will bring the best labor return to the corporation. Thus far the student engineer courses seem to be fairly well established at quite a number of places.

STUDENT RECORDS

18 One of the important features of these courses is the keeping of systematic records of the students. Probably the most satisfactory method is to hold the foreman of each department in which the students are employed responsible for the records of their departments. These records should be turned in weekly to the superintendent of students whose duty it is to keep them on file and enter the individual reports of foremen upon cards made to cover the entire course. Such a system places the foreman much in the position

with reference to these young men, as their instructors were while in college; it has the advantage not only of giving the officials of the company full information, but tends to interest the foremen in the students and to lead them to do all they can to maintain this practical post graduate college work.

19 The following record is a general form such as is kept by the General Electric Company and shows a satisfactory arrangement.

NAME	CHECK NO.	ENGAGED	LEFT
Doe, John	23	3-21-05	3-22-06

Section	Time spent in section		Day or night	Technical ability	Industry	Promptness	Accuracy	Energy
	from	to						
Marine.........								
Government...	3-21-05	5-21-05	D	B	A	A	B	B
Induction Motor								
Slow speed	5-21-05	8-20-05	N	B	A	A	A	A
Floor..........								
No. 16.........	8-20-05	12-17-05	N	A	A	A	A	A
Transformer ...	12-17-05	3-22-06	N	A	A	A	A	B
Railway Motors.								
Turbine........								
Special........								
No. 23, etc								
Berme bank....								
Calculating.....								
Switch-board...								
Resistance meas								

Address, 320 Hulett St. Home, Albany, N. Y.
Notify Mr. John Doe, 23 Hawk St. Home, Albany, N. Y.
Nationality: American. Age: 22. Class of work, special.
College: Eureka College, 1904.
Inst. Books spec. 732 OK. A. C. D. C. Trans. Tur.
Rheo. C. B.

The grade reports are made by the foremen of each department, and are entered upon the young man's card in the record file. The grades are specified in letters and A is a higher grade than B. On the reverse side of the card are columns for absences and their causes, rates of compensation, work desired, and positions held by the student after leaving the course.

20 Such a system as this shows quite clearly the capability of a young man, and enables those who are employing men on the regular staff of the works, or those who are sending them to customers, to make selections intelligently. It might be desirable to add two columns to those given upon the record card above, namely, neatness and tact.

21 In the early history of these courses apparently little system was applied in the following up of the young men, and there was danger of the boy who did not have much self assertiveness becoming lost in some department where he had learned to do some one thing to the satisfaction of his foreman. In all such cases, where the young man had sufficient aggressiveness to go to the proper officials of the company, he was usually able to have the difficulty rectified. Nevertheless, the lack of system in this regard was a serious weakness, both from the standpoint of the corporation and the student. For instance, in the early days, I frequently had young men who were pursuing the student courses write me stating that as far as they could observe, the result of their best endeavors was apt to go unheeded and their chances for advancement were slim. Of course, this was an exaggerated feeling of the young men, thrown as they were among thousands of skilled workmen, and not a true statement of the facts.

22 On the other hand, in student courses which lacked careful centralized supervision and a system of individual grading it was difficult to advance the young man with discrimination and judgment. This frequently gave the showy youth an advantage over the diligent and thorough workman.

23 Not only should such records as spoken of above be kept, but the foreman should be made to understand that it is his duty to see that the young men have become sufficiently well trained in his department before they are permitted to be transferred to other work. In the case of students of a special aptitude, the time required could well be shortened from that of the average schedule, while in other cases it might be necessary to give double the ordinary length of time. This, in fact, is similar to the method taken in colleges: thus, if a young man fails in applied mechanics while pursuing the subject with regular classses, he must either repeat the work in another class, or employ a tutor to take him over the subject again. A man, who after having thus attempted a subject is unable to show the proper preparation, had better be advised to change his collegiate course to some other line. Likewise a young man working in one of the departments of a student industrial course should be followed just as carefully and if he shows himself incompetent to learn the business, he should be promptly dropped, or transferred to different phases of the corporation service.

THE FOREMEN RESPONSIBLE—MENTAL TRAINING

24 In connection with this subject of keeping the records of the young men which, more or less, involves the development of the fore-

man into the capacity of an instructor, I wish to suggest an extension of this corporation teaching which has not always been developed to its greatest possibilities. It would be wise, both for the boy and for those employing him, if the foreman or superintendent should assume even more of the attitude of instructor than is now the case and require the young man to be prepared to regard questions about his duties. Thus, for instance, a young man might be working on a transformer test and obtain entirely satisfactory and accurate results, but at the same time he might fail to expend the energy necessary to think out and understand exactly why and how the various steps were taken—it is far easier merely to follow directions. A few pertinent questions from the foreman would quickly discover such lack of depth upon the part of the student, and likewise the knowledge that he was to be so questioned would undoubtedly spur him on to reach deep into all the work he had in hand. Also in the machine shop a few questions as to the use of the cutting tools which were being used and concerning the character and strength of materials in the product, etc., would tend to develop a quality of observation which would be of the greatest service, not only to the student, but to the corporation after the man had reached a position of responsibility. This method could be developed to quite a high state of efficiency with advantage to all concerned, including the foreman. It would be well to let the foremen know that his duty to follow up and get not only material but also mental results would be one of the bases upon which he himself would be judged. Training of this character would give additional data for record which would frequently develop the strength of a quiet man over that of his fellows, without which he might not for many years be discovered.

STUDENT ENGINEERS' CLUB

25 In the engineering apprenticeship courses we come to another phase which, I believe, is equally full of possibilities for improvement. Thus, some of the larger corporations which have had student engineer courses established for some years have clubs for the men where they may meet together socially and also where lectures of a technical nature designed to be especially helpful are delivered. The Westinghouse Company, I understand, is at present erecting a very handsome edifice which is to subserve this purpose. Up to the present time, so far as I know, such educational work has been voluntary upon the part of the young men. An energetic, active, ambitious boy will obtain all that is possible, while many another good

fellow who needs a little spur will neglect this part of his duties. These clubs are most useful in that they furnish a place where young men can get together with the more experienced engineers of the company and discuss problems of engineering without restraint. They also furnish a social side of life which is delightful and which tends to improve the *esprit de corp* of the whole student body. This latter is essential to the success of any corporation.

REQUIRED MENTAL WORK

26 A further great step in this important educational movement which we are considering, I believe, will be to extend the mental work much further. The voluntary leaders and the informal discussions of the clubs will undoubtedly continue, but in addition there will be compulsory work. Courses of study lying side by side with the practice in the shops and factories will be laid out and will be directed by men thoroughly capable, not only from an engineering but also from a pedagogical standpoint. The corps of instructors, headed by a trained teacher of engineering, will be drawn from the suitably prepared men in the engineering departments of the corporation. The young men will be required at stated intervals, having been set mental tasks parallel to their practical work, to appear at regular class periods before the members of their corps of instructors and take such quizzes and receive such special explanations as may be found desirable. Such an advance in the educational movement as this must perforce appeal to every educator and will, I believe, appeal to the practical engineer. A young man will not be left to himself to permit his mind to wander away from the consideration of the problems which will transform him into an efficient engineer, but he will be under a constant spur tending to lead him to improve his mind in a way to insure his future usefulness. It may be argued that too much of this kind of study, which of necessity will be done after a day's work would overburden the boy and in that I am fully prepared to agree; but it is not necessary to carry the work to that extent. Such a mistake would be made only by an over enthusiast who lacked a knowledge of pedagogical principles, and it is well here to state with emphasis that this movement is entirely too important to the industrial classes of the United States and is too much in the line of pure education for the pedagogical side to be neglected. I believe that future development will find men in charge of this great work of preparation who will be engineers trained not only in the sciences, but in the theory of leading as well. Even

in our technical colleges it has only been within a few years that the importance of the engineering instructor being a trained teacher has become fully understood. Now, the call for such preparation is evidenced by college presidents giving thought to the selection of men with reference to their teaching as well as their practical ability. I have seen many cases where men, thoroughly successful as designers or in other positions in the industries, have utterly failed when endeavoring to impart their knowledge to college classes and to furnish the inspiration necessary to cause their men to get the best out of their studies.

27 In this teaching, a great amount of time need not be taken from the regular shop work since these young men are college graduates and they are, therefore, fully enough developed to carry on post graduate study with comparatively little spurring or explanation upon the part of the instructor. Possibly, a meeting by the instructor—preferably with each man individually—once a week would be sufficient to lay out and comment upon the work to be done and to question upon that already accomplished.

WILL IT PAY

28 The crucial test of every innovation in the industries is, of course, the question, will it pay? The courses developed as they are to the present day seem to be worth while; at least such is the bulk of the evidence that has been obtained from the somewhat extended investigation of the writer. It seems that the courses which pay best, to recapitulate some of the statements given previously, aim primarily to prepare men for high grade engineering duty; the return in labor received during the course being held as a secondary consideration. Such courses employ only college graduates—giving preference to those technically trained—at a wage upon which a young unmarried man can exist without loss of self respect if he is not extravagant. Sometimes a bounty is paid at the end of the course, but its utility is questionable. The length of most of the successful courses is about two years and during this time the student is made more or less familiar with the details of the entire business by being moved from department to department. The foremen of the departments are expected to teach the processes to the students and make frequent grade reports to a central authority. Careful records are kept of the character and standing of the students. Clubs, lectures, and publications are furnished, largely at the company's expense, for the purpose of teaching them and of inspiring them to an enthusiastic interest in their work.

29 Long time contracts are, as a rule, either not called for or are largely a formality, as students are not wanted who do not care to stay of their own volition and who are not interested in and loyal to their work.

30 Such courses as these seem to give satisfactory returns, financially, by furnishing a loyal body of highly intelligent engineering talent for the managing and engineering corps of the organization.

31 Will such courses pay when they become still more collegiate in their nature by adding required scientific mental study, as suggested earlier? Though it is understood that the study would be carried on in the evenings, from one to three hours a week should be given by each student to his instructors and a large amount of the company's time would be expended by the instructors themselves. Experience is wanting to answer the question, though a school for ordinary apprentices, maintained by one of the western railways, bears somewhat upon it. This school is carried on with the aid of the instruction papers of a large correspondence school. Regular instructors have been appointed and time is taken from working hours for the class work. The foremen with whom the boys come in contact and other officials of the company join in highly recommending the movement, not as a philanthrophy only, but as an excellent business proposition. It is claimed by concensus of opinion that the added intelligence and interest of the boys more than pays the expense, while at the same time a body of unusually well trained workmen is preparing for the service of the company. In this school arithmetic, algebra, drawing, etc., are taught.

32 Suitable mental training will be less expensive to compass for the college apprentices than with the younger boys in the school just spoken of, and should yield even more beneficent results. The highly improved training obtained by those who are able to graduate from these improved courses should more than compensate for the slight *per capita* extra expense involved.

33 The instruction force could undoubtedly be kept in excellent condition by now and then giving some of the younger members a year's leave of absence for the purpose of teaching in the technical schools. This would be a mutual advantage to factory and school which could be augmented by such men exchanging positions temporarily with the regular college instructors. The Pennsylvania State College in its electrical department has already taken steps toward obtaining such teaching relations with the industrial companies to which it furnishes students, and it is believed that excellent results will follow.

ARE EXTENDED STUDENTS' INDUSTRIAL COURSES NECESSARY

34 It has already been shown that student engineer courses have grown to their present proportions on account of the positive need of men more highly trained than is ordinarily possible through the self education of the so-called practical man. As courses are today being inaugurated in various divisions of the industries in large numbers, their necessity in the present state of the arts seems fairly well established. But are not these courses now sufficiently advanced where found in their most perfect form? Is further expense as I have proposed devoting to their further development justified? The logical sequence of the growth of both industries and practical education in the United States for the past one hundred years seems to answer in the affirmative.

35 During the first part of the nineteenth century a man of ordinary mental strength could easily understand almost any of the industrial processes of the day. A farmer and his family could do their own manufacturing and could maintain their own transportation lines. The horse was the accepted source of power. Later at the time of the Civil War—the time of the passage of the Land Grant Act—industrial conditions had become more complex. The steam engine had become a common burden bearer and was already doing wonderful things. Our people were becoming less bucolic. Shops, factories, iron mills, railroads, telegraph wires were spreading over the country with unimaginable rapidity. Yet enough sufficiently well trained men to guide these budding industries came from the few unusual boys who worked their way unaided from the bottom to the top and obtained their scientific training incidentally. Technical schools were then little in evidence, but the need of something of that kind was beginning to be felt.

36 Consider now the present time. Compare, if you will, with the earlier period the vast railroad systems, the enormous steamships, the great power plants, the manufacturing establishments—each requiring the services of thousands of workmen—the gigantic mining operations, the intricate telephone systems reaching into every hamlet of the country. The change in the economic condition is even more remarkable than was that from the first to the middle of the nineteenth century. The technical college has come. The simple and practical engineers' collegiate apprentice course is here, aiding in drawing together bands of technical men probably outnumbering and exceeding in proficiency any earlier engineering organization in the history of the world.

37 But already the industrial complexity of life is multiplying so rapidly that a still higher class of brains must quickly be supplied. Every day gives evidence of this fact. For instance, as this is being written, the new steamship Lusitania is making a great burst of speed which will probably lower the record across the Atlantic by several hours. But to do so she had to have within her hull a power plant large enough to light and heat a large city. This is but a single instance of the rapid progression along all technical lines. Every appearance indicates that during the next few years there will be an insistent call for many men of the highest mental preparation. These men must be partially trained by the industrial interests themselves, seemingly in much the manner I have outlined in this paper. It will pay to begin this work now.

THE DUTY OF THE TECHNICAL SCHOOL

38 The argument may be maintained, and with some show of plausibility, that the government should bear the expense and trouble of educating its people. So far as possible, I believe this is so, but the college or university must, to a large extent, confine itself to the teaching of the fundamental truths of nature and cannot to any extent teach the details of each specific branch of industrial business. This latter instruction with much of the "theory" that accompanies it must be given in the shop, mine, or factory.

39 The college can do much to improve conditions by giving extended courses of five and six or more years as is done in the form of post graduate collegiate work today. But to encourage young men to thus further prepare themselves, the industries must offer some consideration. At present the six year college man usually starts with the same compensation and in a position of the same grade as the four year man, which is certainly discouraging and unfair. Such a condition is injurious both to the college and industries and should be rectified.

AMERICAN INDUSTRIAL SUPREMACY

40 When the whole social and industrial fabric of France had been beaten down and destroyed by one of her brilliant but disastrous wars, she rose in prosperity, almost Phoenix like, largely through a system of practical education closely allied to her industries. Many other historical instances might be cited where such education has for a time made a nation a world leader. The spirit of the Land Grant Act and the close relation it has formed between education and the

industries has already done much, I believe, in giving the United States her strong position among the nations of the world. The leaven of that spirit will work yet further by bringing these two elements into much closer accord, not only in the higher grades of education, as herein suggested, but also by the magnificent movement that is now just stirring our political institutions and which is destined in the form of a wide spread system of industrial education to prepare every man who works with hand or brain of every grade "to perform justly, skillfully, and magnanimously all the offices" to which he may be called. Let us hope that as the nation thus grows in industrial perfection, it may also grow in appreciation of pure culture and art.

DISCUSSION

DR. H. S. PRITCHETT[1] Professor Jackson's paper touches, as it seems to me, a most vital question in our industrial and educational work. We all recognize that the education of the high-grade engineer in this country has been well looked after. We recognize with equal clearness that the education of the foreman and the mechanic has been practically neglected. The work which Professor Jackson describes is intended to be a link between the technical colleges and the industries and to serve the needs of the class of men to whom I have just referred. It is an interesting spectacle in educational development that this problem should be undertaken by manufacturers and that, up to this time, they have shown more interest in the matter than have the school men. Those who remember the beginnings of engineering education in this country realize that in the movement for higher engineering education, which took place some forty or fifty years ago, it was the school men who moved first, and a long time elapsed before they were able to obtain from those who employed engineers much recognition.

2 I venture to make this single suggestion. All of us realize the pressing necessity for some solution of the problem of industrial training. If America is to hold its own in the world, its citizens must be trained to become effective economic units. That end will, in my judgment, be gained only by coöperation on the part of those who teach and of those who employ the young apprentice and the solution of the problem will be possible only by securing at the same time the coöperation and good will of those who are to be taught.

[1]President of the Carnegie Foundation for the Advancement of Teaching, and of the Society for the Promotion of Industrial Education.

Prof. Dugald C. Jackson The gentleman who prepared the principal paper for this evening obviously has an axe to grind. It is an axe the grinding of which is of the utmost value to the industries. He wants the great manufacturers to coöperate more heartily in the training of the young men who go into their employ and who are expected to become men of importance in the executive and engineering ends of the establishments. This is desirable. Indeed it is necessary for the best life of the industries. It is being done in some establishments, but it ought to be done in many more.

2 I have another axe to grind. It looks quite like the other gentleman's axe. At least the handle looks quite the same. But it is ground to a somewhat different edge. My complaint is that the industrial establishments and the engineering schools are not holding close enough together. Professor J. P. Jackson speaks of exchanging instructors between the instruction forces of an engineering school and of a great manufacturing company. That would be useful, doubtless, but it is only a drop—a touch and go—toward what is really needed. In Germany there have been close relations between the technical schools and the manufacturers, and the professors and manufacturers have coöperated in the most intimate fashion. The difficult problems of the manufacturers have been worked upon and worked out by the professors, and, in many instances, the professors have been the honored advisers of the manufacturers.

3 The situation is quite different in this country, and it seems to me that our condition is to the serious disadvantage of the industries and also to the work of the engineering schools. The question is, How can this situation be improved? The fault has been on both sides. The engineering faculties have been faulty in being commonly made up of inexperienced young men who are idealists. The latter characteristic is important, and in fact is essential, but it needs to be balanced and squared by experience. The right men are difficult to obtain and the engineering schools have failed to hold out any ultimate place of distinction comparable to the responsibilities borne.

4 Then again the engineering schools have worked their men to the limit of their physical endurance on the immediate duties of instruction, and often of very elementary instruction at that. These have been serious faults of the engineering schools, and there also have been faults on the side of the manufacturers. Some of the engineering schools are now rectifying their faults, and the question is—What should be done to bring the engineering schools and the industrial concerns into more intimate dependence? That such a result would bring important light to the industries, I feel persuaded those

of you who have pondered this question will agree. But the question is how to bring the result about. It can be done, I am sure. It only requires the proper kind of coöperation—coöperation which may call for some getting away from constrained ideas on both sides, but a kind of coöperation which can be brought about to the advantage of both parties.

5 I recently had the honor of drawing a resolution which was passed by the Society for the Promotion of Engineering Education, in which this Society and certain other societies of coördinate importance are invited to join with the Society for the Promotion of Engineering Education in studying this and related questions. I hope that this Society will accept the invitation extended to it

6 Now, there are two more questions to which I wish briefly to call your attention. One of these questions relates to the graduate or advanced study of engineering to which the writer of the paper refers. The majority of the young men who go through the engineering school courses have obtained all of the engineering training of the academic kind which they are capable of assimilating. But there is a considerable proportion, which may be as large as a third of the students graduating, who can profit largely by a year or even two years spent in properly supervised graduate study. I say "properly supervised" advisedly, as few engineering schools appear to have learned that graduate study should consist of the broad and deep study of only two or three subjects, and the student should be thrown largely on his own responsibility in the study of these subjects and should not be harassed by getting up the details of numerous minor subjects.

7 It is to be remembered that the better engineering schools are not trade schools, but are truly professional schools. The industrial corporations ought to appreciate men who have had this additional study under proper auspices and should place them on a distinctly higher level than the men who complete the undergraduate course only. This distinction ought to be made because the young men who have had the benefit of the graduate study under proper supervision are originally picked men and their graduate study, if properly arranged, inevitably adds greatly to their self-reliance, initiative and ingenuity. My experience differs from that of the writer of the paper, as I have found that the industrial organizations desire to employ the men who have followed graduate study in the courses that I have had to do with, and do give them recognition in advance of that given to men who have only completed an undergraduate course. On the other hand, it must be remembered that

very few of the engineering schools possess concurrently all of the requisites for successful graduate instruction, namely, a teaching force sufficiently strong in numbers and in experience, and adequate space and laboratory facilities.

8 The last question which I have in mind to refer to relates to the so called Davis bill now pending in Congress, which has as its object the appropriation of money from the National Treasury for establishing manual training high schools and agricultural high schools in each of the several States. It thus purports to fill the place which the funds derived from the Morrill Land Grant Act, referred to in the paper of the evening, might have filled, had they not substantially all gone toward the maintenance of the distinctly scientific instruction and research in agriculture and instruction in engineering. The Morrill Land Grant Act may properly be named the greatest influence that has been produced in purely American educational processes, but it was a fortunate condition—fortunate for the nation—that the processes built up as the basis of that act have been of relatively slow growth and have not out-run the development of educational sentiment and expert educational knowledge in the land.

9 Also, it is notable that the results of the Act are most strongly in evidence in some of the Western States where the colleges enjoying the benefits of the land grant funds have grown up with the State and have been kept close to good educational practices because a proper educational sentiment and expert educational knowledge has developed along with the college growth. It is quite another thing to appropriate seven or eight million dollars per year which are expected to be matched by an equal sum appropriated by the individual States, and require this money to be expended on a particular educational endeavor for which methods have not yet been perfected or an educational sentiment developed.

10 I believe that such an appropriation might be wisely made if it were conditioned upon the expenditure in each State being made under the advisory direction of an expert State educational commission or commissioner. The Davis bill fails to make such a provision but contains the vicious probability of the money being spent under the direction of independent county boards reporting to the United States Secretary of Agriculture. This is a matter which I commend to the attention of the members of the Society when they are in communication with their representatives in Congress. They should insist upon the insertion in the Davis bill of a provision that money appropriated by that bill shall be spent only under the advisory

direction of an expert educational commission or commissioners appointed in each State.

MR. BASSETT JONES, JR.[1] The Morrill Land Grant Act states that such State institutions as may be founded under the terms of its provisions shall be organized "to promote the *liberal and practical* education of the industrial classes." Perhaps without the intention of the promoters of this act, this unfortunate bifurcation of the object of education has become an established fact. Colleges for the inculcation of a so-called "liberal education" have, both in meaning and results, become distinct from the technical schools providing a specialized education in purely technical fields.

2 A liberal education is practical when it gives the student an altruistic aim and purpose in life, regardless of the particular field to which his energies are devoted. A technical education that is not liberal in this sense is not practical. The time is ripe for us to give a broader meaning to the term practical, when used in connection with education than that generally applied to it by public opinion.

3 The so called liberalizing studies should not be made separate from professional studies, but connected with them in every possible way. Political and social economics, for instance, have been deeply affected by the advance of science and engineering, and this aspect of these topics is the one to be accented in schools of technology. The engineer has also perhaps been the prime maker of modern history. The study of engineering history and its bearing on the solution of modern engineering problems has been strangely neglected, yet the historical method is likewise the method of engineering, and, in fact, the only sane method of attacking problems so deep in their effect upon society as are those of engineering science.

4 Technical teachers complain that perhaps two-thirds of the student course is now given over to subjects not connected with engineering, and that any further broadening of the course of study would be positively injurious. But is it not a fact that the primary difficulty lies rather in the approach than in the material? There is too little emphasis on the *connection* between those studies that are purely technical and those that are not. Each teacher specializes too much in his own field without any consideration of the relations of his subject to those that the student is mastering at the same time. "Why," says the student, "am I required to study history in an engineering school." And he gets no answer to his query because he is not made to see the utility of historical study in his professional work and life.

[1] No. 1 Madison Ave., New York.

5 Professor Jackson shows precisely one of the weakest points in engineering education of today, namely, that our schools, failing to liberalize the student's conceptions of nature by direct contact with practical life problems, have been supplemented by what in effect is a post-graduate course organized with a view to remedy this defect.

6 The question is whether it would not be possible to organize the teaching system so that it will overcome this defect. Is it not possible to require the student to devote at least three of his four months' summer vacation to actual money making labor, under the mutual supervision of his college and employer? The material advantage gained by the student who adopts the method of supplementing the school semester by a period of actual dealing with the life conditions of his profession is very evident. He gives something which no teacher can give and no school provide—a sound judgment—without which a man is not worth his salt.

7 One great advantage of such a combination of study and application would be to clear from the student's mind that which leads to a distinction between what is called a theoretical man and a practical man. A *theoretical man* is one who lacks definite experience in the limitations of fact. A *practical man* is one who lacks education in the development of ideas. One lacks circumference; the other lacks diameter, and the net result, in either case, is a lack of balance. A man who is to be more than a mere mechanic must have a theoretical knowledge of fundamentals. On the other hand, the man who lays claim to a special knowledge of theory—one who is disposed to jeer at experience, as many young graduates are—soon finds in the absence of controlling facts his inability to achieve concrete results.

MR. C. W. CROSS[1] With special reference to the college man as an apprentice in a manufacturing establishment or a railroad shop, the author wishes to say, after a number of years experience in shop work, he has the very highest respect and greatest possible admiration for the young man who, without the spur of necessity, has the pluck to go into the actual work of the shop after graduation from a technical school. This practice is by no means common, but the notable instances of men who have made a brilliant success of their career prove the wisdom of the plan of actual close contact with shop conditions as the only means of learning the business properly, and at the same time, of learning the most important feature, the handling of men, which can be learned only in this manner.

[1] In charge Apprentice Courses, New York Central Lines, New York.

of the arithmetics have seen their error; short practical books are again on the market.

7 This criticism is friendly; the author graduated from what he considers the best technical school in the world, and he wants this school to have a part in solving our present industrial problem, which is one of the most serious this country has ever faced.

MR. C. B. REARICK One weakness of technical schools is a tendency to encourage men to proceed with studies in engineering when they have no natural inclination in that direction. It is not always the schools themselves that encourage it, it may be the parents, or it may be from a number of different sources, but very often they try to make an engineer out of a man who would make a better doctor, or a better lawyer, or a better business man, and if there were more conscientious work in weeding on the part of the technical schools, which have such timber in the early stages, perhaps our technical men would have a higher standing among the manufacturers.

DR. FRED. W. TAYLOR It appears to me that in the discussion of Mr. Jackson's paper perhaps two of the most important elements in the training of college graduates and students who come into industrial life have not been touched upon.

2 The intellectual life of the student, up to the time of his leaving college, has been almost exclusively that of absorption. He has been learning how to get and assimilate knowledge of various kinds. He has learned perhaps a few and perhaps many facts and principles which will be useful to him later on, but if he has really done well he has learned how to go about quickly getting and assimilating whatever facts he may need in the solution of any particular problem with which he may be confronted.

3 Briefly stated, again, his education up to the time of leaving college has been learning how to absorb. After leaving college and throughout the rest of his life his chief concern will not be absorption, but construction; he will have to learn how to put what little knowledge he may have into effective, practical, every-day use, so as to obtain definite results.

4 The chief function, to my mind then, of any shop work which the college student should do, either during vacation or immediately after leaving college, should be, not the acquisition of additional information, but learning how to successfully use what information he has. The graduate or student who starts to work in a shop should go there filled with the idea that he must learn how to do a good

ordinary day's work. The average young man, on leaving college, however, is still under the impression that it is most important for him to gain additional information. Four-fifths of the work of the engineer, or superintendent, or manager, is dull, and monotonous, and demands first of all the ability on the part of the man to endure plain, ordinary, disagreeable work. At college, while the intellectual work of the student is often severe, it is always interesting, and presents at least the attraction of novelty and a certain stimulating excitement. That of the successful engineer or manager, however, is monotonous and commonplace by comparison, and in their college training they have not been taught to do work of this sort.

5 The chief mistake, then, to my mind, which is made by the young college graduate who comes into a shop, and also by many of those who prepare the shop courses for these young men, is that they have their eye on the least important element in the shop training. In my judgment, many unhappy hours would be saved to the students and months and years of partial failure would frequently be saved them, if they came to their shop work with the idea clearly fixed in their minds that they are there primarily to learn how to do an ordinary day's work in straight competition with workmen who are earning their living.

6 Next in importance to learning how to work, to my mind, comes the necessity for the young graduate to become intimately acquainted with the view point and methods of thought of the great mass of mechanics who are working for their living. The college man should expect some day to be a leader, and to direct the work of other men, and unless he learns how to talk with workmen on their own level; how to successfully compete with them in doing every-day, monotonous work; and unless he acquires a certain respect and kindly regard for these men, his chances of ever becoming a successful leader are comparatively small.

7 For these reasons the young graduate while he should be given a good variety of work, still he should not be put to work on jobs, specially prepared and selected with a view to having him absorb an additional amount of information very rapidly. He should be given a daily task, right among the mechanics of the shop, and in keen competition with them, and the object of those who are training him should be to see that he does a good big competitive day's work. The young man who succeeds in holding his own in this way with other workmen comes out of his post-graduate shop course with an amount of self respect and also of respect for the men around him which will place him far on his road toward success as a leader.

It is for this reason that, on the whole, the system of apprenticeship instruction described by Mr. Russell as in use in the New York Central shops[1] appeals to me as, on the whole, preferable to that in use in the General Electric and Westinghouse Companies. In the latter companies, if I am rightly informed, the young college men are in competition with one another rather than with the workmen, and the first consideration in their minds is that they are there to absorb as large an amount of additional information as possible.

8 I believe that the young engineer would get the greatest good by taking one year of hard practical work in a machine shop or other industrial establishment right in the middle of his college course; say at the end of the freshman year. He would come back to college from a year spent in this way far more sober, earnest, and determined to learn and make the most of his college opportunities. I am endeavoring to arrange for a plan of this sort by which a certain number of college students will be regularly given work in the shops of a company where daily and severe tasks are given to each man, and where the force of functional foremen and instructors is ample to see that each man does his full day's work, and that he uses only the best methods and implements for doing this work.

PROF. WILLIAM D. ENNIS There are some practical complications in the development of the special apprenticeship system in ordinary machine shops. These shops have no testing departments or other special places particularly adapted for utilizing technical men, but must place all of the men directly in the productive departments, where, as Mr. Taylor suggested, they are on the same basis as the other men. Unfortunately the result is too often that the young college men "are like the chaff which the wind driveth away." Some of the fault of this is with the men, some of it lies with the schools, and not a little of it is attributable to the conditions of organization in the factories. Furthermore, a surprisingly large percentage of the technical men remain and succeed, although, as Mr. Cross intimated, they are heavily handicapped by their diplomas. Of those who do leave, some, of course, leave for better positions. If the technical men were wholly undesirable, manufacturers would not want them, and they certainly do want them. The most notable thing about this question is that these men are wanted, not for engineering positions, but to be trained for what may be called the *line* positions in the industrial army. In the old organization of industry, there was

[1] See paper "Industrial Education" by W. B. Russell, published in this volume.

no systematic training of men for leadership. Leaders developed by a process of natural selection. As has been said, this produced admirable men, but not enough of such men. We must now practice a form of *regulated* natural selection. All manufacturing is engineering. Superintendents and managers ought to develop from among the body of engineers rather than from among the clerical force. In this respect mechanical engineering and mining engineering are quite distinct from the civil or electric engineering professions.

3 The study of the last two branches of applied science results in the production of expert engineers who should thoroughly know one narrow subject and should be able to master its applications to all conceivable subjects. The mechanical engineer, however, usually becomes a part of a factory organization; in which he is required to be a good manager rather than an expert machine designer or power expert. His function is to be able to apply to one specific industry, all of the principles and methods of engineering. To train men who can do this, we must allow them to grow in the manufacturing plant through gradually increasing responsibilities, insisting upon the application of engineering methods at each step. To carry out this program, certain requirements, stated by Professor Jackson, are essential.

4 The manufacturers must be, as they usually are, broad enough to balance a present annoyance against a future gain. The apprentices must be given a fair show, and should be under the general charge of some high grade man, preferably an officer of the company, who will see that they are given the kind of training that is planned for them.

5 By this is understood, not their being retained in some one department where they have learned to do one thing chiefly and well, but their being "shifted" systematically, regardless of considerations of departmental production, in order that they may get the well rounded experience that the manufacturer finds it profitable to give them.

6 The most vital point of all, however, has not been touched upon. Our technical men have a hard time of it for the first few months because they do not know how to take hold. They need teaching in the policies and methods of the manufacturing plant. They should be shown how in actual business affairs it is essential and desirable that every man's work be accurately, constantly and comparatively weighed by a just standard of value. They should learn the principles upon which such standards are established, and that most fundamental principle, that the individual work alone is a small factor in the result, while the coöperative effect of many men

working along different lines toward a common end is an overwhelming factor. To some extent we can teach students the forms of business organization, the principles of business management and correct industrial ideals. Then, when they take business positions, they will more quickly "get hold." The same training ought also to teach them the importance of straight forward self reliant effectiveness and the abomination of half-accomplishment, excuses and philandering.

Mr. H. L. Gantt Mr. Jackson's valuable paper has brought out much equally valuable discussion, and the writer feels with some of those that have already discussed it that a college education should not entitle a man to special consideration but should make him independent of it. In other words, if his college education is of any value to a man, he should on account of it be less dependent upon special privileges.

2 The greatest defects the writer has found in college graduates are: their inability to carry out orders exactly, and their lack of knowledge of how to do a day's work. The writer has found that if he can teach them how to do exactly what is wanted, and how to do a big day's work, they can as a rule soon acquire the special knowledge needed to make themselves very useful.

3 Following this idea, the writer has adopted the practice of giving college graduates simple work of a routine character, but in such quantity as to keep them very busy all day, and has had most excellent results; those that stood the test almost always advancing rapidly.

4 When I was a boy I often heard an old gentleman whom I very much admired tell a story about Stephen Girard. It seems that some time in his career Stephen Girard kept a hardware store in Philadelphia, and on a certain occasion had a grind stone standing on the sidewalk. He hung out a sign "BOY WANTED." Soon a boy applied and was hired. He was told to go and turn the grindstone. The boy wanted to know what he was to turn the grindstone for, and was told that he need not worry about that, he would be paid for it. The boy went out, looked at the grindstone, and went down the street. Other boys were hired, some declined to turn the stone at all and others turned it for a few minutes and quit.

A few days later in reply to a comment made about a particularly efficient boy he had, Mr. Girard replied, "That boy turned the grindstone."

Mr. Magnus W. Alexander Annually the technical colleges of the United States graduate thousands of young men into the industrial field, equipped with the theories of their professions, lacking practical experience, except for the small amount that the college laboratories afford, and generally unable to apply the theories accurately and effectively to the practical problems of the engineering business.

2 In order to adjust this equipment of the college graduate to the industrial requirements, large concerns and especially manufacturers of electrical apparatus, on account of the variety of their apparatus and the rapid development in their designs, have established "student courses," through which graduates must pass before joining the engineering staff of the company. The course usually lasts two years and prepares for positions as designing and estimating engineers, construction and commercial engineers and technical salesmen.

3 The majority of technical graduates embrace this opportunity for laying a broad foundation for a future career and apply themselves earnestly to the work. Some show a disinclination to enter a student course and advance various reasons for their attitude. Unwillingness to work long factory hours for a comparatively small compensation is one of these reasons, which, however, deserves no further consideration; necessity for the immediate earning of a larger income for financial reasons of one kind or another is a more plausible argument; the belief that the college laboratory and shop practice courses eliminate the need of further instruction concerning the handling and testing of machinery is sometimes encountered and indicates a wrong attitude toward and a misapprehension of the objects of a student course. Many times, while admitting the advantages of a training through a student course, the young man contends that much of the two years spent in this way is wasted; a criticism which finds justification in the fact that some student courses are conducted without effective direction, and lack system except in name, thus reducing the course to a time-serving period. No doubt a well conceived and well conducted student course is the best means of initiating the junior engineer into his profession. The system prevailing at the Lynn Works of the General Electric Company is a concrete example of recognized efficiency, and a brief description of it may prove suggestive and may assist in the intelligent consideration of this important and interesting problem.

4 The General Electric Company at Lynn, Mass. manufactures a large variety of electrical apparatus besides steam turbines, centrifugal air compressors and other mechanical devices. The design-

ing of this apparatus and its constant improvement, the supervision of its manufacture and erection, the development of new designs and new applications of the forces of nature, and last but not least, the selling of the product of the factory call for a constant supply of engineering talent and service of a high order. The student course of the company is designed to meet this demand; it admits graduates of technical colleges and trains them during a period of two years. The object of this course is to give practical experience in handling and testing General Electric apparatus; to fix in the student's mind thoroughly the practical applications of the theory he has acquired at college; to enlarge his engineering knowledge; to offer an opportunity for becoming acquainted with efficiencies and characteristics of General Electric machinery and their competitive value by contrasting them with the product of other manufacturers; and generally to develop the young man along the lines of his future usefulness to the company.

5 In order that this plan may be carried out effectively with due consideration for each individual student, a Supervisory Committee was organized about two years ago, consisting of the superintendent of testing rooms, who is in general charge of the student course, and three engineers representing different departments of the works. The committee meets either weekly or fortnightly as conditions may require. Each new student appears before the committee sometime during the first three months of his service, merely to be introduced to the members, who question him as to his future intentions and advise him as to the best way to accomplish the desired end. The committee makes a note of its general impression of the student, who is called again in about six months, when he is examined quite fully with regard to his theoretical and applied technical knowledge, his alertness in taking advantage of the educational opportunities offered by the course, and his general make-up. This examination is repeated usually at intervals of six months, though sometimes oftener, especially in cases when, on account of a previous unsatisfactory examination, the student has been placed on probation.

6 The examinations are conducted by the individual members of the committee, not with any desire to pick flaws in the educational armor of the young man, but rather with the aim of assisting him in his work and pointing out to him the way to success. The committee assumes quite frequently the rôle of a prospective customer: "I have decided to install arc lamps in my factory and have about made up my mind to award the contract to the X Y Co. What have you to say to this?" may be a question put to a student who has

already had experience in the arc lamp department and intends to become a salesman of the company. The way in which he answers will give the committee a cue as to his general character and his probable success as a salesman.

7 One student will present that ambiguous smile that indicates his helplessness in meeting the situation, if not his ignorance; another, in boy-like fashion, will blurt out with his advice that the prospective customer should buy from the General Electric Company, and will then rest, entirely satisfied with his answer; while another, after a moment of reflection will endeavor, through argument, to convince the questioner of the advantages of the General Electric arc lamps over others. The committee feels that in this latter case they are dealing with an embryo-salesman who is now picked up on one or the other of his statements and, step by step, led to explain the theories that underlie the operation of an arc lamp and govern its light distribution. The prospective engineer, on the other hand, may be confronted with an inquiry as to the most desirable motor, electrically and mechanically, for driving a large planer in a machine shop. A quick reply is not expected of him; a few minutes of reflection and then an answer based on scientific argument is looked for by the committee. This question with its accompanying answer gives the committee a splendid opportunity for testing the student's electrical knowledge in many directions, and for discovering his mechanical engineering ability. The committee, however, does not rest satisfied with a discussion of the appropriate General Electric motor for this particular purpose, but endeavors to find out from the student its competitive value with motors of other manufacturers. A reply confessing ignorance as to the characteristics of other motors is allowed to pass only at the first examination without censure. At that time it is pointed out to the student that the reading of the advertising pages of technical magazines and a study of the pictures contained therein will furnish a great deal of information of the work of competing manufacturers from whom, furthermore, descriptive catalogues can be obtained by those who really want them; the importance of keeping alert in obtaining such information is impressed upon the students.

8 Thus each student is treated individually before the committee and is given just that kind of advice that will be of the greatest benefit to him; the correct sizing up of the young man at his first appearance before the committee is, therefore, of great importance. After each examination the members of the committee immediately compare their judgments and acquaint him with their estimate of him and

their advice to him. The committee's opinion, which is not considered final unless unanimous, is recorded in the minutes and a card index of each student gives a running record of his development. Toward the end of the two years' course a final examination of each student takes place, after which the committee endeavors to find a suitable position for him.

9 The practical work of the factory, while directly under the charge of the superintendent of testing rooms, is naturally influenced by the work of the committee. Each student is transferred from one department to another, not according to an iron-clad schedule of time, but according to his efficiency in any one part of his work. Every student is stimulated to get the right conception of his work day by day, by obtaining light on any doubtful point that may arise in his mind. An exchange of ideas with his fellow students in the factory or in an evening's conversation, or the refreshing of his knowledge by consulting engineering books, may clear up his mind on doubtful points; moreover, the superintendent of testing rooms or his assistants, and the engineers of the company stand ready to assist with advice. Such systematic guidance in the practical work in the factory and the supplemental advice of the committee stimulate the student to correlate theory and practice day by day; to think logically and with a perspective of the real issue involved; and to make the most effective use of his two years' apprenticeship.

10 The committee contemplates a further extension of its usefulness. Although it is satisfied that every student who has received his diploma from his college has acquired engineering knowledge, it has frequently been appalled by the utter inability of some students to perceive the right relation between theory and practice, and to reason from effect to cause, though at the same time they are capable of reasoning from cause to effect. It is the intention, therefore, to call together all students, in groups of about ten, for one hour per week, when just such questions as are now put to them in an examination before the committee will be brought up in relation to the successive steps of the practical work in the factory. It will not be a weekly examination, neither will it be a weekly lecture; it might perhaps be called a "seminar" in which the members of the committee and the students may exchange in an informal way practical engineering ideas according to a preconceived program. I feel sure that such effort will be productive of excellent results and will develop a body of young men well trained, both in the practice and theory of the engineering profession, alert, efficient, and, no doubt, imbued with a spirit of loyalty to the company. What more valuable asset

could a company boast of than a staff of engineers recruited from the best elements of such a student body?

PROF. C. F. PARK[1] Four years ago, a new free evening school was opened in Boston. This school was a substitute of the Lowell Institute for its advanced lecture courses which had been given for more than thirty years by professors of the Institute of Technology.

2 Among the different classes in the community there appeared to be one which had hardly received the attention it deserved. It was for this class, the foremen, that the school was planned. These men receive the same education today as the ordinary mechanic, and it was thought that it would be a great benefit to the community at large if they could have some training in the principles of applied science. The difficulty of finding men who can occupy positions of responsibility as foremen is realized by all who are connected with the management of mechanical industries.

3 To attempt however to train young men separately for the position of foremen would be, under the existing organization of labor, an impossibility, as the foremen must continue for the present, at least, to be promoted from among the workmen. Therefore, to give them such an education as is desired, it is necessary to train men who are already working at their trade. With this object the "School for Industrial Foremen" of the Lowell Institute under the auspices of the Massachusetts Institute of Technology was started and is yielding very satisfactory results.

4 The school comprises two courses, one mechanical and the other electrical, and each extending over two years. These courses are intended to bring the systematic study of applied science within the reach of men who are following industrial pursuits and who desire to fit themselves for higher positions, but are unable to attend courses during the day.

5 The subjects in the first year for both courses are: Practical Mathematics (including Calculus); Elementary Physics and Electricity; Elements of Mechanism; and Drawing.

6 The subjects in the second year mechanical course are: Mechanics; Valve-Gears; Elements of Thermodynamics, the Steam Engine and Boilers; Elementary Hydraulics; Testing Laboratory (Resistance of Materials); Steam and Hydraulic Laboratory; and Mechanism Design and Elementary Machine Design.

7 The second year electrical course includes: Valve-Gears; Elements of Thermodymanics, the Steam Engine and Boilers; Steam

[1] Director of Lowell Institute.

Laboratory; Direct Current Machinery; Alternating Currents; Electric Distribution; Electrical Testing (Laboratory); and Laboratory of Dynamo Electric Machinery.

8 It has been the aim to adapt the courses to the needs of the men for whom the instruction is intended and to include the study of those principles with which they are not likely to become familiar in practice, and which will give them a fundamental training in those matters that will be of the greatest value to them in the work in which they are regularly engaged.

9 The school is open to those only who are ambitious and willing to study. The character and amount of the instruction is such that attendance is required for three or four evenings a week, and men who cannot also devote considerable time to study away from the school cannot derive full benefit from the instruction, nor perhaps maintain their standing.

10 To be admitted to the courses the applicant must be at least eighteen years of age, and must pass entrance examinations in Arithmetic, including the Metric System; Elementary Algebra; Plane Geometry; and Mechanical Drawing. In addition to the examinations, considerable weight is attached to the applicant's occupation and practical experience.

11 The instruction embraces recitations, lectures, drawing-room practice, and laboratory exercises; and is given by members of the instructing staff of the Institute of Technology. The success of the instruction is due in part to the fact that it is specially adapted to the needs of the men and is making them more efficient in their regular occupations and qualifying them for advancement along the lines in which they are working. Text-books are used in many of the subjects, but in some of the work, where the instruction differs widely from available books, printed notes are supplied to the students at cost. Many of the lectures are fully illustrated by apparatus and experiments. Written tests are given from time to time, and problems are assigned for home work at nearly every exercise.

12 The courses are undoubtedly severe, and there are probably not a large number of men who are able to carry them. The scholarship of the students and their ability to continue the courses is determined in part by examinations, but considerable weight is given to the term's work. Those who fail to keep well up with the work or to profit sufficiently by the instruction are disqualified to continue the course. Those who complete satisfactorily the required courses and pass the examinations are given certificates.

13 It may be supposed that men who are following industrial

pursuits during the day are not in a condition to receive instruction after their day's labor, and that instruction under such conditions can be of but little profit; but it can be safely stated that for the four years of the school's history the men have spent two hours at the school three or four evenings a week and as many more hours at home in study for a school-year of thirty weeks and have achieved thorough efficiency in their studies.

14 The shrinkage in attendance has been comparatively small. About as many men have been able to keep up with the standard of scholarship as it had been thought wise to teach in one section in the work of the second year. The size of the first-year class has been about 70, and that of the second-year class about 50. Ninety men have been graduated in three classes—about 30 in each class.

15 A great variety of occupations are represented in the school, but usually a few more than half the number of students are draftsmen or machinists. The men have come from about thirty different companies or corporations in the city or the vicinity. Their average age has been about 27 years and nearly all of them have attended high school or have passed through that grade.

16 The occupations of the men in the first class of the school were as follows:

Blacksmith's helper	1
Car repair man	1
Civil engineer	1
Clerk	6
Draftsman	24
Electrical engineer	1
Electrician	2
Electric railway construction	1
Engineer	3
Engineer of construction	1
Inspector, switchboard, wire, meter	3
Instrument-maker	2
Laboratory assistant	2
Linemen or instrument men	2
Locomotive firemen	1
Machinist	14
Manager municipal light plant	1
Meter testing or installing meters	2
Ordnance man	1
Pattern-maker	1
Station agent	1
Telephone engineer	1
Tool-maker	1
Miscellaneous	5
	78

17 These men have attended the exercises of the school regularly; have taken deep interest in the instruction, and have made untiring effort to do the work. This has continued to the end of the course; and, considering the circumstances under which they have worked, the results have been surprising as well as very gratifying.

18 Much attention is being given throughout the country to the training of the technical engineer, but little, if any, to the training of the foreman or the mechanic, and almost nothing is being done to fill in that gap which lies between the trained engineer on the one hand and the partially trained workman on the other. The country is well supplied with technical schools of college rank which are turning out technical engineers; but there is great need of a technical school, of high grade, whose function shall be to train foremen and superintendents, or to fit men to occupy such positions. We have heard a great deal of late years of captains of industry; but the efficiency of the industrial art depends, in a very large measure, and probably to a constantly increasing extent, upon the capacity of its non-commissioned officers; in other words, upon the foremen.

19 President Wilson has said that "Colleges are not planned for the majority; they are for the minority." So this school for foremen is not planned for the great mass of working people but for the minority of that class who are not uneducated but who have been unable to gain a technical education; that class which has the ability and the enthusiasm to embrace the opportunity to gain training in applied science in the evening at the same time that they are following regular occupations through the day time.

20 It was felt when the school was planned that it would be more valuable both to the men themselves and to the industrial community to give this training of high standard to a comparatively small number of men rather than to give training of a lower grade to a large number of men. That there is a demand for this kind of instruction has been demonstrated by our experience. It was felt, also, that a better educated class of foremen would be a benefit to the community socially, as an intermediary class between the employer or engineer, on the one hand, and the workmen, on the other.

21 Such schools as this free evening school of the Lowell Institute would enable men who are earnest and capable, and who are unable to attend regular day classes, the opportunity to pursue a systematic study of applied science during the evening, at the same time that they are working through the day, and to receive training of high grade in the same subjects that are presented in a high grade mechanical or electrical course: training that will aid them to make

more rapid progress and to advance to a higher point than would otherwise have been possible. Training of this kind will not only bring more enjoyment and a higher salary to the man, but it will put his whole life and that of his family on a higher plane than it would otherwise have been. Such men are needed in our mechanical industries.

MR. W. O. WEBBER At the Erie City Iron Works, in 1889–1894, the writer established a system of apprenticeship in which the apprentices were paid a fair rate of wages, sufficient to enable them to live properly on their own income, and besides we agreed in the apprenticeship papers that if the apprentice served his four years faithfully, at the end of his apprenticeship we would give him a set of signed papers showing that he had faithfully performed his duties as an apprentice; that he was a skilled journeyman in the particular line, or lines, in which he had served, and making him a present of $100.

2 This present, or bonus, was in no way deducted from his wages, but was purely and voluntarily a present from the company to the apprentice, to enable him to provide himself with proper tools, clothing, and otherwise the means of starting him out upon the road, if he so chose, as a journeyman machinist, to go elsewhere, or stay with us, if he so elected. As a matter of fact, all our apprentices stayed with us.

3 At the beginning of their third years, if the boys had proved intelligent and satisfactory, they were taken into the drafting room, and part of their four years' apprenticeship consisted of at least six months in the drafting room.

4 The fourth year was considered to be somewhat elective, *i. e.*, the apprentice was given the choice of remaining in the drafting room and completing a draftsman's course, going into the pattern shop and learning the essentials of pattern making, of entering the foundry, or of returning to the erecting shop where the greater part of his fourth year was passed on the testing blocks, making dynamometer tests and taking indicator cards, and adjusting shaft governors, setting valves, etc., or he could return to the machine shop proper, where he acted as foreman's clerk.

5 We also had other apprentices, for instance, in the foundry, who took nothing but an iron molding and brass molding course, excepting that they had the opportunity to work in the drafting room and learn drawings and pattern making; we had also pattern making apprentices who had an opportunity to learn something of

molding. Boiler making and blacksmith apprentices, in the same way, were given opportunities to learn thoroughly all parts of their respective trades.

6 We found as a result that we had a splendid lot of embryo foremen on hand. Some of these boys are now proprietors of their own shops, and are invariably doing well. We exercised great care in their selection, and no applicant was taken who had not graduated at the high school, and who could not pass a pretty stiff examination in the three "Rs." The result was that an apprentice was found to be the only person out of some thousand employees, including those in the office, who could do cube root quickly and intelligently.

7 We always had from a dozen to twenty applications on the books from high school graduates desiring to enter our apprenticeship system. As far as possible we took them in the order of their application, their intelligence and other qualifications being equal, the only exception being that the sons of the employees of the company took precedence over outsiders.

8 These boys were encouraged in every possible way to perfect themselves in the theory, as well as the practice of their trades. The head draftsman established, on his own responsibility, but of course with our sanction, an evening school, to which the boys could go if they so chose. They were encouraged to ask questions, directly of their foreman or the writer, and in fact the writer made it part of his business to have a close personal supervision over the apprentices, which, he found, resulted in the apprentices being a pretty reliable barometer of the discipline and morale obtaining in the shops in which they were working. In other words, what a bright young apprentice doesn't know, and doesn't see, in the shop where he is working, isn't worth knowing.

MR. D. A. TOMPKINS[1] Following a proper education of a general nature and comprising moral, mental and physical training at home or in the kindergarten, and at suitably light work in proper proportion, there comes a period where technical education is begun or where real work is entered upon. Industrial work requires the application of both science and art. The man or woman who is both *instructed* and *trained* is capable far beyond one whose training or education has been one sided, that is, in a college only or in a workshop only.

2 In modern industrial life it is desirable to have the same mix-

[1] The D. A. Tompkins Co., Charlotte, N. C.

ture of actual practical work and of scholastic and technical training. This must of necessity mean scholastic and technical schools within reach of the young working people; it must mean the maintenance of common schools and special schools with teaching adapted to special industries. The common school work and the special school should both be coupled with an apprenticeship system in some practical work. Every boy and young man should have an apprenticeship connection with some practical work, just as the boy on a farm goes to school and yet has always more or less to do with farm work, not generally by design but by force of surrounding conditions.

3 As the cry of the kindergarten teacher is ever to get possession of children at an earlier age, so an apprenticeship is more valuable as the boy or girl is started young. All apprenticeship work of young boys and girls should be as carefully guarded as the kindergarten work of infant children, but it is exceedingly important that the apprenticeship age should be reduced rather than extended.

4 In a plant consisting of a machine shop, foundry and pattern shop, at Charlotte, N. C., the author has developed an apprenticeship system which has been exceedingly satisfactory and productive of good results. The idea at the beginning was to take apprentices at and above 16 years of age, and none younger. All our experience has shown that 16 years is entirely too old. The best learning period has been passed. We have found that the younger the apprentice is indentured the better. We arrange so that each apprentice shall be under a sort of foster-father care of a journeyman. The work of young apprentices is during part of the vacation of the common school term and at such other times as he may be spared. The apprenticeship often extends throughout a college course.

5 The terms of this contract include a designation of the trade to to be learned; the term of apprenticeship, which is three years; and the compensation the apprentice is to receive during the first, second and third years. The agreement continues as follows:

By mutual consent the apprentice may interrupt this apprenticeship service to go to school, but shall not be thereby released from completing this apprenticeship term of 300 days per year for three years, or 900 days all told, exclusive of interruptions or deductions, either on account of school, or sickness, or any other purpose. At any time in the first six months, either party to this contract may cancel it, the first six months being a period of probation.

Two grades of certificates will be given as follows:

The certificate Class A.A. will be given to the apprentice who has averaged 6 months at school or college each year of his apprenticeship. This certificate with a general shop average of 100 being the award of highest possible merit. No apprentice falling below a general shop average of 75 will be given a Class A. A. cer-

tificate even though he may have complied with the requirements of six months at school or college.

The certificate Class A. will be given to those who serve the full apprenticeship term and make an average of 75, or above, but who are unable to attend a school or college as required above.

The General Shop Average for the full apprenticeship term will be determined from the weekly report cards handed in by the department foreman. The averages on the weekly cards are graded as follows:

ATTENDANCE—60 hours per week are 100 per cent.

PROMPTNESS—Prompt during the whole week are 100 per cent.

CONDUCT	**Good, 61 to 100 per cent. Fair, 21 to 60 per cent. Bad, 0 to 20 per cent.**	**SKILL**	**Good, 61 to 100 per cent. Fair, 21 to 60 per cent. Bad, 0 to 20 per cent.**
DILIGENCE	**Good, 61 to 100 per cent. Fair, 21 to 60 per cent. Bad, 0 to 20 per cent.**	**ACCURACY**	**Good, 61 to 100 per cent. Fair, 21 to 60 per cent. Bad, 0 to 20 per cent.**
RAPIDITY	**Fast, 61 to 100 per cent. Medium, 21 to 60 per cent. Slow, 0 to 20 per cent.**		

It is desired that each apprentice shall take a vacation of one month in each year and spend it, preferably, on a farm in the country.

Each apprentice is assigned to a selected journeyman mechanic who will look after his welfare and his training.

The apprentice may be discharged at any time for such cause as dishonesty, misrepresentation, grossly bad conduct, disobedience, gross neglect of duty, or other similar offenses.

The apprentice may quit at any time if wages are not paid, or if he is ill treated.

6 The foregoing relates to industrial education where common schools and colleges are used for scholastic and technical training in regular courses. Practically the only fault to be found with the colleges is that they are not accessible except to a limited class. The colleges and universities with their immense endowments are within the reach of comparatively few. The difficulty is threefold, *a* they are inaccessible to the working youth, *b* the cost of the prescribed course is beyond his reach, and *c* the usual course of four years must be taken bodily out of the working life of the young man. The same is true of State supported institutions. The colleges and universities stand above the working youth and refuse to give that special scholastic or technical training. Indeed some of the endowed colleges and universities and some of the State supported ones lay such stress upon the importance of a four years course of scholastic technical training that they actually spoil what might have been, with some practical training, a very capable man.

7 That there is a field for a more widely diffused education, within reach of the working youth, is made plain by the growth of the

modern correspondence schools; by the wide field of usefulness of the modern business college where a boy or girl goes to learn some specific thing well enough to make a living; by the success of the educational departments of the Young Men's Christian Association and the Young Women's Christian Association; by the necessity in big modern manufacturing corporations of operating special schools often within the works and by the schools founded by and in the big department stores. In most of these cases, even in the Christian Association educational departments, the instruction received is paid for at full cost. This is nothing against these institutions and it is to their credit that they give to the working people that supplemental instruction so essential to make the common school education practical in earning a living. The only reproach is that with all the gifts by philanthropists and all the appropriations by States, the tendency in the institutions founded and maintained by them, the education rarely, if ever, reaches the real working boy or girl. There is, with a vast number of working people, a little gap between their common school education and that leavening education which qualifies the young man or young woman to "make a living" for themselves and become far more useful to the community. The filling of this gap may, in some cases, be accomplished through the correspondence schools, the business colleges, or other schools but for the young man or young woman who is in manufacturing pursuits it would be infinitely better if a system of special instruction and training could be operated in the midst of the homes of the working people. To be most useful such schools would have to take instruction to their very doors; the hours must suit the working time and the instruction must not interfere with the regular work nor diminish the regular wages of the working boy or girl.

8 In the past the college has given an excess proportion of mental training, while the boy or girl who has to work and cannot go to college has an excess of practical training. In the field of common school and college training it is exceedingly desirable that a practical apprenticeship be coupled with the school and college course, and that for the boy and girl, in fact, also for young men and young women there should be schools of special instruction located in the midst of the homes of the working people with subjects taught which relate to the particular trades in the neighborhood.

9 Further appropriations by States and further gifts from philanthropists would accomplish much more for the general cause of education and for the advancement of civilization if a part were applied to such practical education than if given to institutions

already heavily endowed, for making higher education come still higher. The writer, far from deprecating any form of higher education, thinks it is questionable whether, after reaching a certain point of cost, any further expenditure does good, but rather does harm by increasing costs.

10 An apprenticeship in early life which would entertain the child, as children of the farm are interested and entertained by taking a light hand in the work of the farm, would save the child from drifting away from a taste for work and would give an apprenticeship at an age of quickest impressions.

11 If, in addition to such apprenticeship, on going to work, the youth could spend evenings and other spare time in schools which would still further increase the usefulness of the common school and apprenticeship training, then the value of the man would be increased three to tenfold.

MR. G. M. BASFORD It is not pleasant to sound a discordant note in the discussion of a paper so carefully and thoughtfully prepared, but, speaking from the standpoint of one who has worried about this question in an organization of 21,000 men, it seems vitally necessary to point out an error which is now serious and will certainly become more serious. It is well to provide for college men in industrial organizations but the experience of the past thirty years has proved and present experience is proving every day that the vital need lies not in college men but in the shop workmen upon whom we depend for output and for those things which may be summed up in one word—"results." It is well to provide for the college men; it is, however, a mistake more serious than most of us can now realize to provide for them unless we have previously put our shop recruiting system for the workmen—the men who do our work—upon a proper basis. I cannot find the words to say, as it ought to be said, that college graduate apprenticeship is wrong from every standpoint unless based upon and preceded by a proper recruiting system and what we generally understand by the term, "regular apprenticeship."

2 If we have a proper regular apprenticeship system we have a moral right to deal with college graduate apprenticeship. If we have not such a system, we have no such right and we are making an error for which we shall in time pay dearly. It is easy to realize that this is not a popular sentiment to express, but a warning is evidently needed lest we build our pyramid upon its apex. We stand in need of captains and a few subordinate officers, but we stand in greater need of an intelligent rank and file. In developing the

first class let us not kill the second. If we had a good organization as to the rank and file, the captains and subordinate officers would not constitute a problem. It is from the rank and file that we always have and always will develop leaders. We shall suffer in the long run for any policy which tends in any way to discourage ambition in the large class of men upon whom we must rely. The best we can do for an industrial organization and for everyone who enters it is to put recruits upon an actual rather than an artificial footing, allowing everyone to make his place in the organization in competition with everybody else. The company already alluded to has for two years made a practice of taking college men in as workmen at a living wage with no promises and no special privileges. The plan is working well and promises well.

Prof. A. A. Hammerschlag[1] I had no idea I should take part in this discussion, but I feel I owe it to Professor Jackson of State College to give a different point of view on the subject which has been discussed. The function of the technical school or college, as described in the paper, lays too much emphasis on the benefit to the industries and too little on the duty we owe to the individual. Technical education should primarily be devoted to the development and training of the individual; the interests of the industries are incidental and of secondary importance. The industry, by reason of its economic plan, its position and its power, invariably cares for itself. The student cannot be cared for if we try to serve two masters, one the industries and the other the student—they are diametrically opposed by their selfish interests. The industry is going to buy as much as it can for as little as it can, if it is a well-organized, efficient, financial corporation. The student is going to get as much pay as he can as soon as he works and therefore, it seems to me, we must begin with a hypothesis whose financial aspects are such that we must face them in discussing the question of industrial apprenticeships.

2 I have had an opportunity during the last two or three years to come in intimate contact with a great many apprenticed students in the Pittsburg district, and I am going to say this, that I believe that the apprenticeship courses are run for the benefit of the industries and not for the benefit of the students that take the courses, and that the rate of pay to these students makes it impossible for them to live the right kind of life after giving sixteen or eighteen years of time to study and preparation. With living conditions where they

[1] Director of the Carnegie Technical School, Pittsburg, Pa.

are now, it is not possible for a man to live for two years on 10 to 15 cents an hour, which is rather less than we pay the average laborer for digging trenches. Service on this basis destroys his loyalty, and if the industry does not get his loyalty, it does not profit by the student whom it has apprenticed.

3 Another phase of the apprenticeship question makes it objectionable to graduates; it is a paternal system—it raises class and caste in the shop. It makes the men and the foremen resentful when they note the relationship between these students and the employer, thereby destroying harmony and good will. It likewise has this very definite fault; it is narrow as an educator; it teaches the student merely one manufacturer's output, therefore, it is evident to any employer that the experience and knowledge gained commands only a narrow market and if that is his sole recommendation, to a competing manufacturer, the student finds it almost impossible to get employment that is lucrative.

4 This student organization apprenticeship course in the industries seems to me to have this additional defect, it is demoralizing to the student himself—like a man who is being nursed; he has been leaning on his parents all through his life at school and he finds he still needs someone to help carry his burden. It makes it difficult for him to develop his character, and see the result of his educational preparations. What the student needs more than anything else is something to individualize him, and there is nothing going to make a man of him unless it is hard and keen competition. I don't know how men's characters can be developed unless they are compelled to fight their way. It seems to me that what we need particularly in the industries, and what we need particularly in the technical schools, is a better understanding of the essential training and education which a student needs to succeed immediately after graduation in holding his own with less prepared individuals.

5 Professor Dugald Jackson of Massachusetts Institute of Technology and Professor Park of the Lowell Institute, discussed another phase of this question, dealing with a clearer understanding between teaching staff and practicing engineers, so that we may be able to supplement in the school what the industries fail to give—a species of coöperative education. Personally I feel that this movement which has occupied our attention is nothing more or less than a grave criticism of our technical educational system, and it has led the industries to adopt a reversion to the old world type of the apprenticeship. It is crude and medieval, but it is effective. Now, if it is effective, why not profit by some of its good points? I believe, however, the safest place to put this system into practice is not with those of

longest school preparation, but with those of only partial preparation, bringing about thereby active coöperation between the manufacturer and the workman. It seems to me what we have to do is to give these men who are ambitious, who have ability and aspirations, a chance to rise; and then for those who have completed a technical course to ask the industries to take them on their face value.

6 If we fail in this, I feel we are spending too much money on our school trained men, and too little of it in training those who must of necessity be trained in the industries.

7 In response to the other discussion I would like to state that the Carnegie Technical Schools have had a most cordial coöperation and assistance by the industries in Pittsburg, and my remarks were not made with respect to coöperation in that district, but they were made with the hope that those who planned courses of this character would do well to pause and meet this problem with the consideration that it deserves.

Mr. Calvin W. Rice I want to state my own experience, because I think it is different from what Dr. Hammerschlag has said.

2 I started with about fifteen other fellows who happened to be in my apprenticeship, and worked for 10 cents an hour, and lived on it nine months; I could have lived on it two years, if necessary. I paid $1.25 a week for my room, and $3.25 for my meals on a weekly ticket, and I had left a couple of dollars for spending money. To be sure, I had my clothing when I started, but this item did not cost much because I wore overalls all the time. It was popular to be poor, and I think it is possible now, as I know it was then, to myself and friends, to live on 10 cents an hour and be respectable, and to get washed up after the day and make a social call in the evening like any other person.

3 These are facts, and I have been through the experience. After having served nine months as an apprentice I was promoted to foreman, first at $9 per week, and then $12, and as such I have handled probably several thousand young men who have passed through departments under me. Each of those young men received 10 cents per hour. They were certainly alive to their opportunity and the majority developed the very traits which Dr. Hammerschlag says must be developed in order to be men. In less than two years, which was the length of the course, the average man was promoted out of it and into a practical position. The facts are, I think, that rarely does a man remain through the two years. He is sometimes promoted out of the course in six months into a position of responsibility. The

demand for good men is very great. They are sent out on jobs very soon after they have learned even a smattering of the assembling of parts and the operation of machines. They are also sent out to install apparatus; they meet the men of affairs in the world who are purchasing the apparatus, make friends, get offers of good positions, and immediately go from a position of ten cents an hour to a position of $15 or $20 a week, on the outside, and it is impossible for the parent company to keep them.

4 One of the reasons which the parent company has for paying this low wage, is that the mistakes that are made are very expensive. I have seen a young man make a mistake in connecting up a dynamo, that was worth perhaps two or three thousand dollars, causing its destruction. There was no punishment. If he were discharged, a promising man was lost to the company, and the amount of damage could not be taken out of his pay.

5 Admitting that manufacturers for selfish reasons train men for their own company I feel that they are doing a practical service and are achieving the desired results. Now, I ask for information. Specifically what do you want? From each of the speakers of the evening there has been a request for coöperation. I think, if you are going to make progress you should specify the kind of coöperation you want that you do not have now.

6 I am personally acquainted with the men in several of the larger companies that are carrying on these courses, and they are exceptional men to whom the word "coöperation" is a life motto. Now, I know if there is anything lacking that you can suggest specifically it will have very careful consideration.

7 Further, you know very well, that the professors of the colleges are welcome any time to take their students to the factories and stay there a week or longer. On the other hand the practical men at the manufacturing establishments are delighted and feel honored by being invited to come and give lectures at the colleges.

8 Again, men from the Society consider it a great honor to be called on to serve on boards of visitors. One of our Council considers it a great honor to serve on the Board of Visitors to Brown University, to visit the mechanical engineering department. Here then are the manufacturing interests, the colleges, and the societies desiring to coöperate, and I think this meeting will accomplish results if the gentlemen here, and we have a splendid representation, will name specifically what is needed.

MR. H. F. J. PORTER In order to arrive at the solution of any given problem in the shortest possible time, it is always desirable to divest it of all the extraneous unnecessary and misleading features which surround it.

2 The problem before the Society is, as I understand it, How shall the industries secure their skilled workmen?—and Prof. J. P. Jackson proposes that the colleges coöperate with the student engineering courses, which he has described as already existing in manufacturing establishments and in which he sees great promise.

3 Technical education is not a new subject for discussion in this Society. It came before it at its first meeting in 1880, and I trust it will be brought up as often as the times seem to warrant its consideration. New fields of industry are continually opening up, inviting workmen to enter them, but as practice must always precede theory, so the courses preparing technically skilled workmen for these fields must inevitably lag behind the demand for such workmen, and the needs of the changing situation must continuously demand attention.

4 Looking backward over the history of the development of industry during the past fifty years, I think that technical education has taken its part so far pretty well. The question is—How shall it continue? Let us examine Professor Jackson's proposition. (The italics in the following quotations are mine.)

5 In the first place, taking his premises,—The closing sentence of Par. 8 states: "For eight or ten years such student engineering courses in the industries have been springing up *in large numbers all over the country.*" The closing sentence of the succeeding Par. 9 states: "Today, *on account of this new type of post-graduate industrial education,* every young man who has received his bachelor's degree and who has a fair modicum of brains and common sense has fields innumerable which lead to positions of responsibility and usefulness, etc." Par. 34 states: "Student engineer courses have grown *to their present proportions* on account of the positive need, etc." And again, in the closing sentence of Par. 36: "The simple and practical engineers' collegiate apprentice course *is here* forming and drawing together bands of technical men, probably *far outnumbering* and outclassing in proficiency any earlier organization in the world."

6 Now, let us see the basis of Professor Jackson's statements regarding this great educational development in the industries. He says in Par. 7: "Early in the past decade . . . . certain far-sighted managers connected with the Westinghouse, General Electric and

Western Electric Companies and other industrial concerns had been employing some of these men (who were being graduated from the scientific colleges) and were putting them through a more or less rigorous course of preliminary training." Three are here specifically named, but the latter of these I know personally had no student course. Again in Par. 12 and following he quotes from letters received from men now directly in charge of young graduates at the works of the General Electric Company, Westinghouse Electric and Manufacturing Company, Fairbanks, Morse and Company, Allis Chalmers Company, Western Electric Company, Stanley Electric Company, Union Switch and Signal Company, Baldwin Locomotive Works and The Pennsylvania Railroad Company;—nine in all, including the three previously mentioned, but of these I know that only the first two have student courses.

7 Four years ago while I was engaged in reorganizing a department of the Westinghouse Company, I suggested to Mr. Downton whom Professor Jackson mentions as being in charge of their students' course, that he write an article on his department for the "Engineering Magazine," which he did. At that time he corresponded with other concerns about the country to learn what they were doing and found only the General Electric Company doing the same thing. He found that the Brown and Sharpe Manufacturing Company had an advanced apprenticeship system as did the Baldwin Locomotive Works and R. Hoe and Company, but no students' courses such as Professor Jackson describes.

8 In a recent issue of the "Engineering Magazine" appears a very comprehensive article on "The Present Status of Apprenticeship Systems." From this I quote: "In a few plants an effort has been made to *systematize the mode of employing, instructing aud promoting apprentices*. The classic examples in America are Brown and Sharpe Manufacturing Company, R. Hoe and Company and Baldwin Locomotive Works." And again, "Of American factory schools there are but a very few worthy of serious considerations. The apprenticeship schools of R. Hoe and Company, of New York, The General Electric Works, at East Lynn, together with the Casino technical night school, conducted in connection with the Westinghouse plants are the notable schools of this sort."

9 Recent inquiries of my own corroborate this information, namely, that there are really only two such student schools in America, those of the General Electric Company and The Westinghouse Electric and Manufacturing Company. The reason for this is very evident when we look into the facts of the case.

10 In these days of close competition no ordinary commercial or industrial enterprise can afford to establish and maintain a technical school. Education is expensive. The technical schools about the country are all poor and constantly soliciting donations. Unless it can be reasonably assured that its student body would remain with it permanently no enterprise of the kind referred to can afford to do any educating except to the extent of developing the skill of its employees in their special craft. The two companies mentioned above, however, are not of the ordinary kind. They stand in a class by themselves. They openly state that they purposely educate young men whom they do not expect to stay with them, in order that they may act as future salesmen. Quoting from the letter in Par. 13, which Professor Jackson received from the man in charge of one of these schools, the last paragraph of this letter states: "In fact we are just as anxious to have a good man with our customers as we are to retain them in our employ." And the man in charge of the other says in the fifth paragraph of the letter in Par. 14: "Seventy-five per cent of the men will be given positions of responsibility in the company's service or be placed by the company in electric lighting or railway work, which is quite to the company's advantage, since the young men will be in the field with a thorough knowledge of the products manufactured here."

11 I do not know of any other industrial concerns in the country who manufacture a commodity which so specializes its workers that after they leave their employ they are fitted only to become consumers of it in the same field. This field is practically monopolized by these two companies, and naturally a man who has been educated to use one type of this commodity will incline to advocate it when the opportunity presents itself. These companies can well afford to fill the country with well educated salesmen to whom they pay no salary.

12 But these two concerns educate their students along electrical lines only. Professor Jackson has been misinformed if he supposes that there are other concerns that are doing this same line of educational work in other fields. He says that every young man who has had a bachelor's degree, etc., can on account of this new type of post-graduate education, take this course, and yet I am given to understand that there are from 1000 to 1200 students' names on the lists of applicants for admission to these two schools alone. Where are the other schools to which the other many thousands of young men with bachelors' degrees can go? It is possible that they exist, but I have failed to find them.

13 If all the industries were as fortunately situated as the electrical, Professor Jackson's reasoning would apply, but they are not.

14 R. Hoe and Company, Brown and Sharpe Manufacturing Company, Baldwin Locomotive Works, Warner and Swasey, The McCormick Plant of the International Harvester Company, The National Cash Register Company, The Allis Chalmers Company, The Santa Fe Railroad, The Colorado Fuel and Iron Company, and many other industrial establishments have apprenticeship systems, but such systems, not quite so well organized, have existed for years. The National Metal Trades Association has formulated a set of conditions which is recommended for incorporation in its members' apprenticeship agreements for their improvement, and they are very elementary. But such improvement is not by any means the postgraduate technical education that Professor Jackson means. His premises in stating his solution of the problem are based on misleading data, and merely confuse the discussion.

15 Competition is compelling every enlightened employer to secure the best help he can and improve it all he can with the means at his disposal. And what are those means? First: local trade schools as for instance, in New York, the Cooper Institute, the Achmuty and Baron de Hirsch Trade Schools, that of the General Society of Mechanics and Tradesmen, and others; in Brooklyn, the Pratt Institute and the Polytechnic Institute; in Philadelphia, the Franklin Institute and the Drexel Institute; and the Williamson Free School of Mechanical Trades, Williamson School P. O., Pa.; the Boston Trade School, that of the Massachusetts Charitable Association and the Mechanic Arts High School, in Boston; the Ringe Manual Training School, Cambridge; the Technical High School, Springfield; the Artisans School, Syracuse, N. Y., of which our Professor Sweet is director; the Armour and the Lewis Institutes and the John Worthy School, Chicago; the Maryland Institute, Baltimore; the Tuskegee Industrial Institute, Va.; the California School of Mechanic Arts, San Francisco. The above are examples of many that are scattered generously over the country.

16 The Pennsylvania Railroad, the New York Central Railroad and many others use the Young Men's Christian Association. Correspondence schools are doing coöperative work.

17 Professor Jackson need not despair of the lack of sources for securing instruction for ambitious employees, if only the latter are fortunate enough to have an enlightened manager who will encourage them to take advantage of their opportunities. But if Professor Jackson will encourage colleges to establish courses in the art of

management he will come very close to reaching a solution of the problem in hand.

18 The majority of the factories in the country are not fit places for self-respecting mechanics to work in. They are dark, badly ventilated and unsupplied with the ordinary amenities of modern civilization. The foremen are illiterate and know nothing of the principles of economic management. They are practically slave-drivers. They say to the operatives: "What right have you to think? I will do the thinking; do as you are told and do it quick, that is what you are here for." Such conditions do not tend to encourage employees to seek for means of self-improvement.

19 The paper of Mr. W. B. Russell on "Industrial Education" which deals with the Apprentice System of the New York Central Lines, is to my mind very much to the point. Paragraphs 3, 17, 20, 21*a*-*b*-*i*-*j* and 22 contain certain principles which must be recognized as essentials by the management before any kind of instruction can be effective. As Mr. Russell says: "In comparison with these, mere details of the apprenticeship system are absolutely insignificant."

20 A few colleges have already established schools which are preparing men to fill the managerial field. The Chicago University, the University of Illinois, the University of Pennsylvania and the New York University, each has a school of Finance and Commerce. Stevens Institute has a course in Business Engineering. The Clarkson Memorial School of Technology, at Potsdam, N. Y., has for five years been doing splendid work along these lines.

21 The human element must receive at least as much attention as the inanimate machinery which is so carefully preserved and kept in order.

22 It has been said that selfishness is man's dominant attribute and that the sooner we recognize that fact the better we will understand the human nature with which we have to deal and will save time and money in striving for ideals.

23 If this be true, then the colleges should teach that enlightened selfishness will pay better than mean selfishness; that the ethical principle in the golden rule is an economic principle.

24 Let the colleges teach that the one difference between a machine and a man is that one has no brains and the other has, and that it will pay to utilize the potential knowledge which those brains possess.

25 Let the colleges teach that the way to meet competition is by strengthening one's organization by development instead of weakening it by squeezing its life out by brutal arrogance.

26 Let the colleges teach that if the American industrialist does not take a broader view of the field than is presented to him through his shop window or by looking over his back fence, he will awaken some day to the fact that his sordid selfishness has caused him to yield to the enlightened methods of Germany.

27 Let the colleges teach the manager to give attention to the health, the morals and the mental development of his workingmen, and he will find that healthy, sober, intelligent workmen will prove to be eager for self-improvement and will turn out more and better work, even under ordinary management, in light comfortable and cheerful rooms than will cheap ignorant help in dark cold rooms under a score of half-frozen functional foremen. The Massachusetts Board of Education is now laying a foundation in these directions in its primary, secondary and high schools, which is worthy of adoption by the colleges.

28 By the adoption of these fundamental principles of social economics and the knowledge of modern methods of scientific business management every industrial establishment will become an adjunct to the college; a blessing instead of a curse to the community in which it is located; and a potent force in the nation, tending to forward its advance toward permanent commercial and industrial supremacy.

MR. W. F. HENDRY Referring to Mr. Porter's remarks on Professor Jackson's paper concerning "student courses" in various large manufacturing establishments I would state that the Western Electric Company has an educational department and the practice of hiring young men and putting them through a regular course of training has been followed by us for many years.

2 In the New York factory we have four broad types of student courses.

a A course to fit the student to hold executive positions in general.

b A course to provide men to fill such positions as assistant foremen, telephone engineers, shop office department heads, inspection department, etc.

c A course to provide men for executive positions in the office or clerical branches.

d A course for young men or boys who wish to learn a trade.

3 In addition to these there is the regular summer course for college men who wish to put in not less than eight weeks of their vacation at practical work.

4 The first and most important is the four year contract course which is open to graduates of colleges or technical schools with a degree equivalent to B.S. In order to show that the training is by no means all electrical, I will give the curriculum.

Punch press department	4	weeks.
Drilling department	4	"
Screw machine department	12	"
Milling department	8	"
Pattern making department	4	"
Brass foundry	3	"
Shop store rooms	3	"
Shop order department	3	"
Nickel plating department	3	"
Tool room	38	"
Assembly department	12	"
Inspection department	8	"
Blacksmith department	4	"
Cabinet making department	4	"
Switchboard wiring department	12	"
Outside installation work	12	"
Drafting department	12	"
Shop cost department	4	"
	150	"

5 The student is put to work on a screw machine, drill press or milling machine, adjacent to and on precisely the same basis as the regular workmen, working on a day rate or piece work rate. Many cases are on record where the student has made as good wages as the regular workman. They are not however kept on any one job more than three or four days, the idea being to give them as many different operations as possible.

6 It is seen that nearly a year is spent in the tool room. Before the student leaves this department he makes from raw material several jigs, punches, dies, etc., which must be perfectly commercial articles. Here he also obtains experience in the proper design of tools in the tool drafting branch of the tool room.

7 In order to insure thorough routine, the student fills out the regular time tickets which after having passed through the pay roll department are sent to the head of the educational department who thus has a constant check on the men and knows just what they are doing.

8 The students all belong to the Western Electric club which meets in this building once a month, at these meetings papers are read and discussed. In addition to this, they receive a monthly talk

or lecture by some department head on general manufacturing or engineering topics.

9 Among many others the following positions are held by graduates of the student courses of the New York factory:

10 Superintendent, Antwerp factory; Assistant head of design engine department, New York factory; Assistant manager, Tokio factory; Chief engineer, Berlin factory; Head output department, New York factory; Assistant head inspection department, New York factory; Manager, Antwerp factory; Master Mechanic, Tokio factory.

THE AUTHOR In closing the discussion, I desire to correct a few wrong interpretations, that were taken from my paper.

2 Prof. D. C. Jackson said I had "an axe to grind," and I had. My suggestions are exactly in line with his argument, that we should have more coöperation between the industries and engineering schools. The paper deals with one practical phase of such coöperation: the joining of both these interests in the making of a technical, or business, engineer.

3 Prof. Hammerschlag says, in Par. 5, "For those who have completed a technical course * * * ask the industries to take them on their face value." This is just what I ask. The technical graduate is not, and likely never will be, immediately upon graduation, ready to step into a position of responsibility; therefore, let the industries which alone are able, by reason of their equipment, give the needed additional preparation. Prof. Hammerschlag says that my paper neglects the individual. I am unable to understand where. He also says that the special apprentice, or graduate student engineers' course "raises class and cast in the shop," makes "men and foremen resentful," "is narrow," "is demoralizing * * * like a man that is being nursed," pays less than "for digging trenches," "destroys * * * loyalty." Are these not theroetical statements based on conventional premises? Such conditions should not and need not exist; nor do they, where I have made an examination. Mr. Hammerschlag's argument against such courses is much weakened by the statement that immediately follows: "the Carnegie Technical Schools have had most cordial coöperation and assistance by the industries of Pittsburg, and my remarks were not made with respect to coöperation in that district." Does he mean that graduates of this school only get generous, broad treatment by the Pittsburg industries? Or is Pittsburg the only district in which technical graduates get such treatment?

4 Mr. Porter's discussion is largely based upon a supposed error in my statement and a misconception of the purpose of the graduate

student engineers' courses. If he will inquire more seriously (Par. 7), of the various companies named in my paper, he will find established courses, as I represented; and if he goes further in his investigation, he will find other courses of a similar character, both established and in course of development. Thus, I must insist that my premises are correct, as the evidence in my hands is incontrovertible.

5 His second mistake is his thought that the object of my paper was to show how the industries can "secure their skilled workmen" (Par. 2). After this statement, practically all his arguments, other than those intended to show that my facts are wrong, are based on the assumption that the apprenticeship courses dealt with, are for the training of mechanics, rather than engineers, and certainly not for college men. This is fully evidenced by the courses (Par. 14 and others);and the trade schools (Par. 15 and 16) referred to by him.

6 The "fundamental principles," or instructions to colleges, named by Mr. Porter in (Par. 18 and 20 to 27), have not been unthought of by students of applied pedagogy, and those of utility have been in more or less general use for some time.

7 Mr. Rice is a man who has evidently gone through such a course as I described; and, as a result, is thoroughly competent to speak upon the subject. In the main, he upholds my contentions; and is my best witness to the usefulness and success of the educational movement under consideration. Mr. Tompkins' excellent discussion upon the shop training of workmen deals largely with the apprenticeship systems for other than college men and, therefore, does not directly enter into this discussion.

8 Professor Ennis and Mr. Taylor apparently have a clear conception of the problem as it appeals to me. Most of the suggestions they make are of a nature to aid in the development of technical courses for graduates such as will tend most surely to turn out in the end good engineers or staff officers. There seems no good reason why in such courses the man cannot be taught the meaning of a "hard day's work," learn to read the thoughts and "feelings of the workmen" in the shop, and be brought against suitably "keen competition" (Mr. Taylor, Par. 5, 6 and 7).

9 Mr. Jones shows clearly the gap between the end of the college course and the position of responsibility in the industries. His suggestion that this gap may possibly be filled by modifying the college courses cannot, in my estimation, be answered affirmatively. It may be lessened, but some real contact with an industrial organization will always be required before the graduate is prepared for his true function. If this contact can be obtained in the shops before graduation, excellent; but why not, at least in part, after?

10 Messrs. Alexander and Henry describe useful student engineer courses; their remarks are worth careful study. The suggestions of Messrs. Cross, Rearick, Gantt, Basford and Russell show the necessity of sympathy and helpfulness between the industries and colleges, and I may add that the latter are fully ready to listen to the needs of the former, and to endeavor to meet them.

11 It has been stated in this discussion that, if the workmen are suitably trained, there will be evolved from their ranks plenty of good officers. I absolutely disagree with that statement, however much I feel the urgent need of industrial education for workmen and I aver that much of the rapid advance and improvement, throughout the whole range of industries of this country and Europe, is in large measure the result of collegiate technical education. It might as well be suggested that the Army and Navy give up West Point, Annapolis, and their various practical officers' training schools with the belief that, if the rank and file are excellent, all needed officers would automatically develop.

12 Permit me to reiterate that my paper deals with the subject of *making officers for the industries*, be they line or staff. I incline to believe that college men appreciate thoroughly the need of preparing men for the *business* or *staff side* of the industries, as well as the technical, and are modifying the college courses with that object in view. The purpose of the paper must not be confounded with the magnificent movement now on foot in this country for the proper *training of skilled workmen*, both by industrial schools and apprenticeship systems. The student engineers' courses, now in existence, can and will, undoubtedly, be greatly improved upon; but they are now performing, however crudely, a necessary function. As a proof of their success, I find that large numbers of men who have taken such courses have, almost uniformly, quickly risen to positions of responsible usefulness. My plea is that these practical training schools for officers are of great utility; and deserve careful attention from the managers of industrial corporations: further, that their proper development requires a scientific, practical knowledge of both shop management and pedagogy.

No. 1161

A HIGH SPEED ELEVATOR[1]

BY CHARLES R. PRATT, NEW YORK
Member of the Society

The type of elevator selected for the new Singer building and for the tower of the Metropolitan Life Insurance building is known as the Gearless 1 to 1 Traction Electric Elevator, the driving mechanism for which is a motor located over the hoistway, with a traction sheave and a brake pulley on its armature shaft. The ropes from the car pass over this traction sheave, down under an idler sheave, and again over the traction sheave and down to the counter-balance, giving two half traction turns over the traction sheave to drive the difference in weight between the car and the counter-balance. This traction has been found to be sufficient in ordinary passenger elevator service, especially in high rise elevators on account of the weight of the ropes and variable counter-balance chains or ropes, the latter leading from the bottom of the car to the bottom of the counter-balance, thus adding to the *constant* load on the ropes leading to each face of the traction sheave, thereby reducing the *variable difference* in traction load caused by the variable passenger load.

2 The diameter of these traction sheaves is about 40 inches, the least permissible for proper wear of ropes, which gives a circumference of 125.6 inches or about 10½ feet, which at 600 feet per minute car speed requires 57 r.p.m. of the hoisting motor. 2000 pounds net load at 600 feet per minute would require a motor of about 50 h.p. which at 57 r.p.m. would be a motor of about 200 h.p. size, cost, weight, etc. The loss of motor efficiency at this low speed is compensated for by the saving in friction loss due to the elimination of all transmission gearing between the motor and the ropes.

3 The brake pulley being the same or but little larger diameter than the traction sheave, requires a frictional resistance of the brake shoes equal to the net load, or the same that is required by a safety

[1] The reader should note paragraph 1 of the author's closure in connection with this paper.—EDITOR.

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two electric motors positively geared to the same drum shaft on his Central London Railway Elevators.

14 All high speed hoisting mechanism can be easily driven by the action of gravity, but if a low pitch worm gear positively geared to that mechanism be independently driven so as to synchronize with its normal motion, a positive speed regulation is established, which not only prevents excess of speed, but assures perfect acceleration, dead lock at stop position, and will come to stop normally upon failure of current.

15 A friction brake on a high speed electric elevator interferes with its operation, lessens its efficiency, and has no positive function of safety. To replace it with a worm gear control on a Gearless 1 to 1 Traction Electric Elevator is a simple matter, *viz:*

- *a* Replace the brake pulley with a worm gear having its worm driven by an electric motor, called the controlling motor.
- *b* Have the worm gear ratio such as to obtain the greatest efficiency in the controlling motor at the greatest range of speed by its field regulation.
- *c* Construct a worm that can not be driven by its worm gear, without reference to how great its lead may be, by making its diameter large enough to keep its angle of thread below 5 degrees, and by large diameter thrust washers. This worm gear has little work to do at high speed and will run cool.
- *d* Connect up the controlling motor in circuit with the hoisting motor so they will synchronize with each other in starting, stopping and speed regulation
- *e* With the motors open circuited, the car gradually and *positively* stops, because it can not drive this worm gear.
- *f* With the hoisting motor open circuited:
  - 1 Driving against gravity with a heavy load, the controlling motor blows its fuse and stops.
  - 2 Driving in the direction of gravity, or with a light load *against* gravity, the controlling motor drives the traction sheave under the control of the operator in the car, and brings the car to its floor.
- *g* With the controlling motor open circuited, the hoisting motor fuse blows, and the car gradually and positively stops, as in case *e*.
- *h* The controlling motor governs acceleration by its field regulation, and the hoisting motor requires no finely graduated starting resistance, which simplifies the control.

i The controlling motor governs speed when driving with gravity, and the hoisting motor requires no armature shunt, this saves direct loss of power.

j The foregoing refers to these two motors being connected up in parallel, the same or possibly better, results may be obtained if they are connected in series, with slightly different action. Either way is standard practice.

16 No experiment is here involved. The combination used involves only principles employed in standard elevator construction; but the combination provides a new method of elevator control more nearly perfect and safer than the best hydraulic.

17 "A chain is only as strong as its weakest link." In a Gearless 1 to 1 Traction Electric Elevator we observe a multiplicity of wire ropes, heavy sheaves and shafts driven by a motor of ample power and held by a friction brake, and then close our eyes to the fact that this motor and brake are alternately deprived of their motive and holding power every few seconds. Should one happen to let go before the other takes hold, the car *falls free* to the bottom of the hoistway, unless stopped by some device. No amount of ingenious electric circuits established for coöperative action between an electric motor and a friction brake, can make either of them a *positive means* to hold an elevator car or keep the car from attaining a dangerous speed. No factor of safety of 10 exists here since neither of these elements has at its maximum a holding power of over twice the load. On the other hand a low pitch worm gear can not drive its worm, nor can a hydraulic valve be placed in a position where the car can travel at a dangerous speed; and when these normal positive elements of safety are omitted from a high speed elevator, disaster is sure to follow sooner or later.

18 Two opposing forces act on the armature of an electric elevator motor, *i.e.*, gravitation and electro-motive force, and between these forces, either incidental to transmission of motion, or for the purpose of stopping and holding the car, are interposed elements of friction, such as worm gears and friction brakes.

19 Under normal conditions the electric motor can start, stop and control the speed of the car, only requiring a friction brake to hold it at rest, or to check it at reduced speed. But such a brake, particularly on a gearless elevator, is a very large and costly affair, requiring very delicate adjustment, and can not be considered to be a positive protection against excess of speed.

20 *Suppose that in place of the brake pulley on the armature shaft, there was placed a worm gear*, with teeth as strong as the brake's fric-

DISCUSSION

Mr. Orman B. Humphrey There are three essential elements which necessarily enter into all installations of passenger elevators, and these, in the order of their moment are: (*a*) *safety*, (*b*) *speed* and (*c*) *economy of operation*.

2 What pertains to elevators for high buildings must also be considered in the equipment of all passenger elevators, except that some of the sub-divisions of these elements of safety, speed and economy of operation must vary in their individual degree of importance when the elevator is intended for service in buildings of great altitude.

SAFETY DEVICES

3 At such minimum car speeds as are desirable in all high buildings we must eliminate certain types of safeties as being not only wholly unfit for use under these increased speeds, but positively dangerous. The safeties referred to are any and all types of sliding wedges, rolls or grips, or other devices which tend to check or stop the car suddenly in case of broken cables or excessive speed in descent. This leaves for consideration such forms of safeties as shall gradually and effectually, but not suddenly, check the descent of the loaded car in case of accident. There are various safeties of this nature, usually depending upon some form of speed governor and fixed governor rope, which accomplish this desired checking and retarding of accidental excessive speed by means of gripping the rails, and with the best of these we are all familiar. All devices which depend upon gripping a greasy rail—unless of the sliding wedge type having more or less sharp teeth to engage the rails or fluted rolls, neither of which can be used for high speeds—will sometime be found wanting. It is not unreasonable to state that the rate of retardation or checking of the car descent with these safeties is more or less variable and at times somewhat problematical. It is for this reason that other auxiliary safeties ought to be included in the equipment of all elevators.

4 Of the different safety devices in use at the present time, the one which appeals most strongly to the writer is that which depends, not upon clamps applied to the rails, but upon series of wires arranged with systems of retarders which in turn become engaged by dogs on the moving car in case of accident, thus gradually checking the speed of the descending car, and bringing it to a standstill without undue jar or shock. This wire friction device, like the

Cruickshank safety, installed on the elevators at the new Hotel Belmont in New York, meets a demand which has long existed in elevator practice.

5 It is not well to depend upon any one device or type of devices, but rather upon several distinctly different schemes for checking accidental fall or excessive downward speed. In addition to various mechanical retarding devices, the best of which should form part of every elevator installation, there should also be a carefully designed air-cushion of at least one-fifth the total car rise.

6 It should be the duty of the legislature in every State to enact laws regulating the number and types of safety devices which should be applied to every passenger elevator. Such legislation should be very broad and cover the entire installation, as to material, design of equipment, car speed, etc. This has already been done to a certain degree in some States, but there is still much room for improvement even in those States already having such legislation.

SPEED

7 The second important question is that of reasonable speed, and under this head we must consider, not only the periods of positive and negative acceleration and actual car velocity, but also any and all methods and devices which shall facilitate the handling of passengers with expedition and comfort. The period of acceleration should be as brief as is consistent with safety, comfort and economy of operation. The stopping of the car should be accomplished within a running distance which should always be under positive and absolute control of the operator, and in good practice it must depend to a certain extent upon the velocity of the car when running at its highest speed. The maximum car velocity should never exceed 600 feet per minute. Legislation controls this in some States. Assuming a maximum 600 feet per minute for express service, it will generally be found advisable to adopt nearer 500 feet or even less for speed on local cars. The writer does not favor excessive car speeds.

8 Much can be accomplished in ultimate despatch by using cars of suitable size and design, and by perfecting the devices which form parts of the car and well enclosure, like those for opening and shutting the doors, as well as having ample door openings; also the facility and certainty with which the up and down signals can be understood by the car operator. It is impossible to deny that to a certain extent the element of safety increases inversely as the car speed.

Therefore while all reasonable speed should be obtained, it should not be accomplished at the expense of the element of safety.

ECONOMY OF OPERATION

9 The economy of operation may best be treated under the different types of elevators, and owing to inherent faults, which appear in the installations in high buildings, the plunger elevator will be mentioned here only to condemn it. For moderate rise it may be well enough, barring the generally erroneous impression regarding its absolute safety, but in the modern high office building it has no place. This leaves but two standard and accepted types of which it is necessary to speak. The horizontal or vertical cylinder hydraulic, and the drum electric, machines.

10 Between the horizontal and vertical hydraulic cylinders there is little choice aside from the individual requirements of different installations governing the amount of room available for the elevator machine. It has been demonstrated that the drum type electric elevator is by far the most economical in operation under the varying loads which must necessarily be handled in high buildings, and the question is often raised whether the relative safety and speed of the hydraulic and electric machines may best be answered by calling attention to the increasing number of the latter type of drum electric elevators which are now being installed. The great improvements made in the past few years in developing the electric machine and perfecting methods of control make it certain that it will be used to the practical exclusion of all other types before very long, even in high buildings where it must meet the most rigid requirements for the highest attainable standard of safety, speed and economy of operation.

Mr. William H. Bryan The traction elevator as now developed promises to be a most excellent machine, and is already giving a good account of itself. It seems to have captured the last remaining stronghold of the hydraulic elevator—the tall building requiring long travel and high speed. It has done away with the burdensome worm gear and large winding drums, and has still further improved operating efficiency.

2 The most serious objection to this type of elevator is the extremely large motor required to give the power necessary at the very low speed to which it is limited by direct connection to the traction sheave. This increases its first cost, and its weight, the latter an important

matter when the machine is placed over-head, the location now generally preferred. Lower motor efficiency and greater space required are further objections. Any design, therefore, which permits high rotative speed for sheave and motor, would appear to be of decided value. The speed of car fixes the peripheral speed of sheave, and the diameter of the latter must be large enough to insure satisfactory adhesion and life of cable. Has the experiment been tried of using a greater number of smaller cables running over smaller sheaves? For instance: the example cited by the author (Par. 2), shows a sheave 40 inches in diameter, speed 57 revolutions per minute. Presumably the cables are $\frac{5}{8}$ inch diameter. Four $\frac{5}{16}$ cables are equivalent to one $\frac{5}{8}$ inch and will give satisfactory results over a 12 inch sheave, permitting the motor speed to be increased $3\frac{1}{3}$ times, or to 190 r.p.m. Why not use the smaller cables, and put in four times as many of them? The same automatic tension adjusting scheme could be used as is now so successfully employed. In such a case the breaking or renewing of a single cable would be a matter of minor importance, thus increasing the factor of safety.

3 There would seem to be no objection to widening the face of the sheaves to admit the increased number of cables. If greater adhesion is desired, so as to do the required work with a single half wrap, thus narrowing the face of the sheave and doing away with the idler sheave, could not the gripping V grooves so successful in Manila rope transmission be employed? The grooves could be made with the usual wood or rubber facing. These, of course, would wear in time and need renewal. Furthermore, very nice design and adjustment would be necessary in order to insure proper adhesion when needed, and at the same time permit slipping when the car or counterweights land on the buffers. Another method of increasing cable adhesion is by magnets, which have been used where one of the cars is intended for occasional use with extra heavy weights, such as safes.

4 The advantages of higher motor speed could also be secured by the use of additional traveling and standing sheaves, as was done in the German-American and Beaver buildings, New York City, and as has been standard practice with hydraulic machines for many years. Higher motor speed might also be secured by chain drive from motor shaft to traction sheave, a device which has very high mechanical efficiency.

5 It should be remembered, however, that this machine is not available for speeds under about 400 feet per minute, such as are ordinarily required in department stores, hotels, and apartment houses. For these a worm gear machine in which the traction sheave

is substituted for the ordinary drum is being used. This type has all the advantages of the gearless machine in positiveness of terminal stops, and has the advantage over it of less cable wear, this resulting from the larger sheave diameter permissible. It is also lower in first cost, weighs less, and occupies less space. Its efficiency however, is probably not quite as great, in spite of the smaller and higher speed motor. It would seem to be fully as available for high speeds and long travel as the gearless.

6 It would seem that some slippage of cable is unavoidable in all traction machines. This, and the necessity of using sheaves of minimum diameter in the gearless type, tend to shorten the life of the cables.

7 The author's proposed additional control by substituting for the brake a miniature worm gear of low pitch driven by an independent motor in speed synchronism with main motor, appears to be an excellent arrangement. It would seem to make such an elevator as safe as any elevator supported by cables can be made. Undoubtedly the worm gear in the drum machine is an element of safety in retarding speed, a fact which seems to be recognized by standard builders in omitting the reserve car brake from geared traction machines. There would appear to be some chance for friction and wear and tear if the motors did not synchronize perfectly. The cost would probably be increased somewhat, as the additional parts would amount to more than would be saved by the omission of the brake sheave. Neither would it seem reasonable than its current consumption should be materially if anyless.

8 While the author's plan involves no elements experimental in themselves, the combination is unique. Unexpected difficulties may arise in practice, and it is hope that Mr. Pratt will put the device into actual experimental service as soon as possible, and advise the profession of the results.

9 It does not appear that trouble need be anticipated from a too sudden stop in case the controlling motor failed on a down trip. As this would be the ordinary and regular method of stopping, the original adjustments would have to be made to suit. Should the hoisting motor still be taking current its circuit breaker would at once open. Old types of steam machines were made with low pitch gears which locked the car when stopped, and which were provided with small flywheels for bringing the car gradually to rest.

10 The locking brake suggested by the author has been criticized for two reasons; 1st. In the event of its failure there would be a sudden and probably destructive stop; and 2d. In the event of lack of

synchronism—which to the writer seems to present some difficulties —there will be friction and wear and tear. It seems to the writer that both these conditions could be met by a slight change in the construction. Instead of making the worm angle 5 deg., or less as proposed, why not make it somewhat larger, so that its function would become more a braking and less a locking? This would practically reproduce the conditions of the ordinary geared machine. Furthermore, a small fly wheel would keep the apparatus in motion for a few seconds after derangement, thus affording a more gradual stop.

Mr. W. F. Hendry The elevator apparatus described by Mr. Pratt is extremely ingenious and interesting, the requirements apparently being fulfilled in a manner quite worthy of the inventor of the screw machine.

2 The arrangement as described is noteworthy for reliability and simplicity, but being intended apparently merely as a suggestion, the paper is quite brief and leaves considerable to our imagination. There are several points concerning which a more elaborate description would doubtless be of interest to the members.

3 For example, in Par. 15, it is proposed to use a motor of comparatively small size to secure, through the non-reversible worm gear, the desired speed regulation of the car. The speed of this "controlling" motor will be variable through as wide a range as practicable by means of resistance introduced in the field circuit. Such motors as ordinarily constructed may be designed for a maximum speed three times the minimum. A motor built with auxiliary commutating poles, and with a low horse power output per pound might be designed for a variation of 6 to 1.

4 If therefore the maximum speed of the car is 600 feet per minute, the lowest speed at which the car will be under control of the operator will be 100 feet per minute. When making a landing he would therefore, after having reduced speed to this figure, bring his car switch lever to the middle or zero position, thereby, through suitable magnetic devices, opening the circuits of both motors. The car will then continue to move at a constantly decreasing speed until it finally stops even with the landing.

5 It seems probable that to secure this ideal retardation by means of a worm gear driven backward, considerable experimenting will be necessary in order to obtain a gear which will allow a reasonable length of run, and yet eventually lock.

6 Under uniform conditions of torque and lubrication this might not be difficult, but the former varies from positive to negative and

attains a value of several hundred pounds in each direction, which condition makes the problem quite interesting.

7 It might be suggested that armature resistance would reduce the speed of the controlling motor, but it should be kept in mind that while the car is traveling up with maximum load, the motor will be taking full load current from the line, and when going down this current will become infinitesimal, so that a resistance to affect the desired result would be somewhat cumbersome.

8 If it be supposed that the speed of the hoisting motor is reduced from 57 revolutions per minute to 10 revolutions per minute by a corresponding reduction of control motor speed, the question immediately arises as to the speed at which the circuit of the former is opened.

9 If the hoisting motor is disconnected too soon, the load thrown on the control motor will blow its fuse, while if disconnected too late, it will blow its own fuse.

10 A very nice adjustment is indicated especially in view of the variable conditions as to amount and direction of the torque.

11 Another question arises as to the details of speed control. If the simplicity is to be retained, pilot motor, and similar complicated controllers are to be avoided, which means that the control motor shunt field rheostat will be located in the car and practically form part of the car switch. All who have operated elevators know to their sorrow how short is the life of a traveling cable; in fact they are usually installed with one more wire than actually necessary in order to have a spare because it frequently happens that a wire will break in the first few weeks of use, though the others may last a year or so.

12 In this arrangement the shunt field wires being in the traveling cable, the continuity of the circuit is in constant jeopardy. Should this circuit be interrupted, the control motor would attain under certain conditions, almost an infinite speed. If the car was on the down trip with full load, the action would be similar to the newspaper stories mentioned by the author. When the operator finally realized that the car was running away, and brought his car switch to the stop position causing the main circuit control magnets to disconnect the hoisting and control motors from the line, the car may easily have attained a speed of 1000 feet per minute and the practicability of retarding and stopping the car, by the means described, without discomfort to passengers would be tried to the limit.

13 It may be thought that the fuse of the controlling motor would blow if the shunt field circuit was interrupted, this however will not happen to this type of motor, if it is running free, or with a very light

load, which would be the case with the circumstances under consideration. Neither would the series winding have any appreciable effect as the current passing through it would be far less than necessary to provide sufficient flux to reduce the speed.

14 The author in closing verbally states that safety of life and limb should not depend upon electric circuits, magnets, etc. and thus implies that the controller for this elevator will be a comparatively simple affair, and that continuity of any circuit will not be relied upon to prevent accident.

15 Under the conditions mentioned above, however, the only means of stopping the car would be the dynamic action of the main motor, either by delivering current to the line or to a local circuit of resistance sufficiently large to dissipate the energy. In either case, the circuit would include magnetic switches, fuses, resistance etc. which the author recognizes as unreliable devices. These and other minor problems are in no sense insurmountable, but the solution thereof must be carefully considered, in order that the simplicity, so attractive in the paper, be retained in the actual machine.

MR. J. W. MABBS[1] It seems to me that the elevator under consideration is a step in the right direction. It undoubtedly adds greatly to the safety of an elevator which by many is considered unsafe.

2 I want to present an elevator that is pronounced by competent experts to be the safest elevator in existence. Safety is undoubtedly the greatest consideration in any elevator; it should be the first consideration, although recently it seems as though some people had departed from this doctrine and had made the matter of safety subservient to other things.

3 The elevator shown in Fig. 1 was designed at a time when there was nothing in the electrical line that could compete with a first class hydraulic elevator or that was satisfactory to the engineering fraternity or public at large.

4 It was desirable to have but one kind of power in a building, consequently there was the demand for a satisfactory electric elevator. The drum machine, the best at the time, was restricted to a speed of 350 feet per minute; had numerous defects; was not a safe machine; was generally unsatisfactory and especially so for high office buildings.

5 The first machine as it is shown here was installed in the Chicago Board of Trade building five years ago, and up to the present time has run about 25 000 miles at an expense for repairs and some changes

[1] Chief Engineer of the Board of Trade, Chicago.

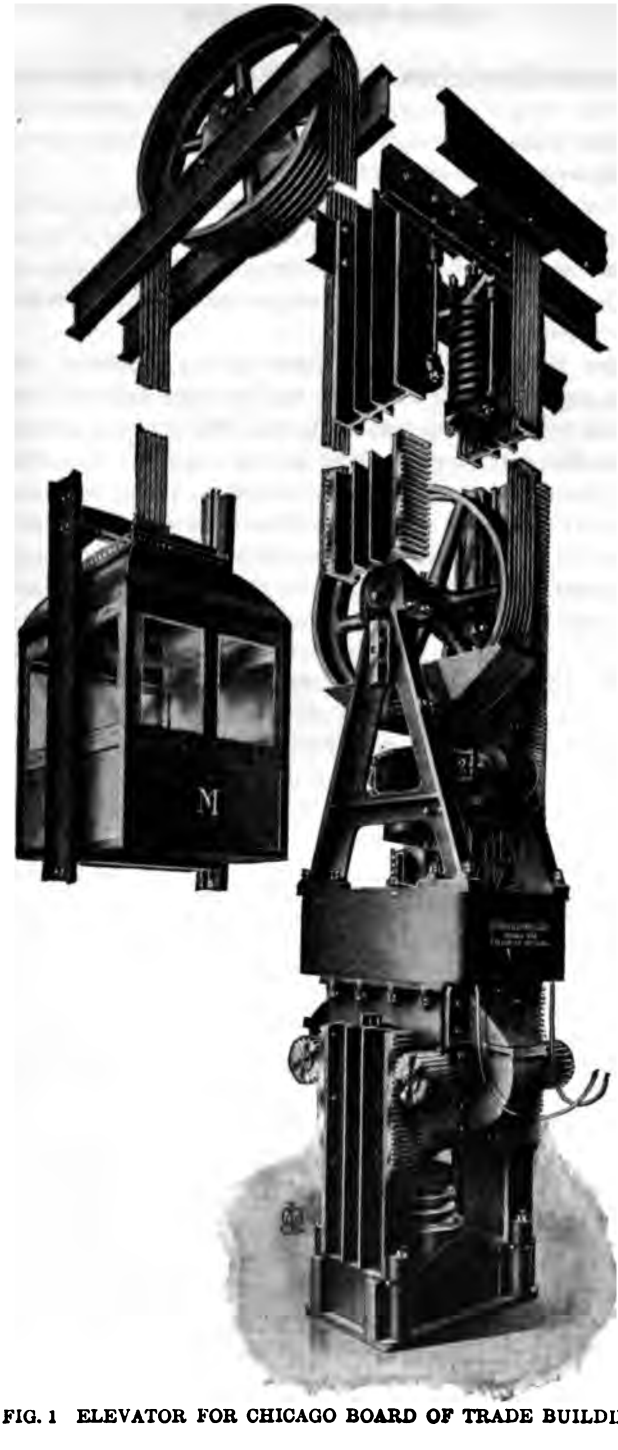


FIG. 1 ELEVATOR FOR CHICAGO BOARD OF TRADE BUILDING

of $432. This includes everything pertaining to an elevator; the signals, lights, gates, hoisting ropes, electric cables, the machine and controller. In other words, the maintenance of this elevator for repairs of every description was about $86 a year. The speed of this car is from 575 to 600 feet per minute, giving absolutely satisfactory service in a building whose requirements were pronounced by one of your most distinguished members, when he was installing electric elevators in it, to be the severest in the United States. After three years of uninterrupted service of the first Mabbs machine, the electric machines referred to above which had proved extremely costly both in operation and repairs and very unsatisfactory generally, were replaced by four Mabbs machines shown in Fig. 2. This view shows the machines in the basement, at the bottom of travel, when the cars are at the top; it also clearly shows the pneumatic buffers which are an absolute limit stop.

6 The principle of this elevator is that the machine constitutes the counter balance of the car, and is the only counter weight. The cables are arranged so that the machine is geared two to one and when the machine ascends the car descends, and vice versa.

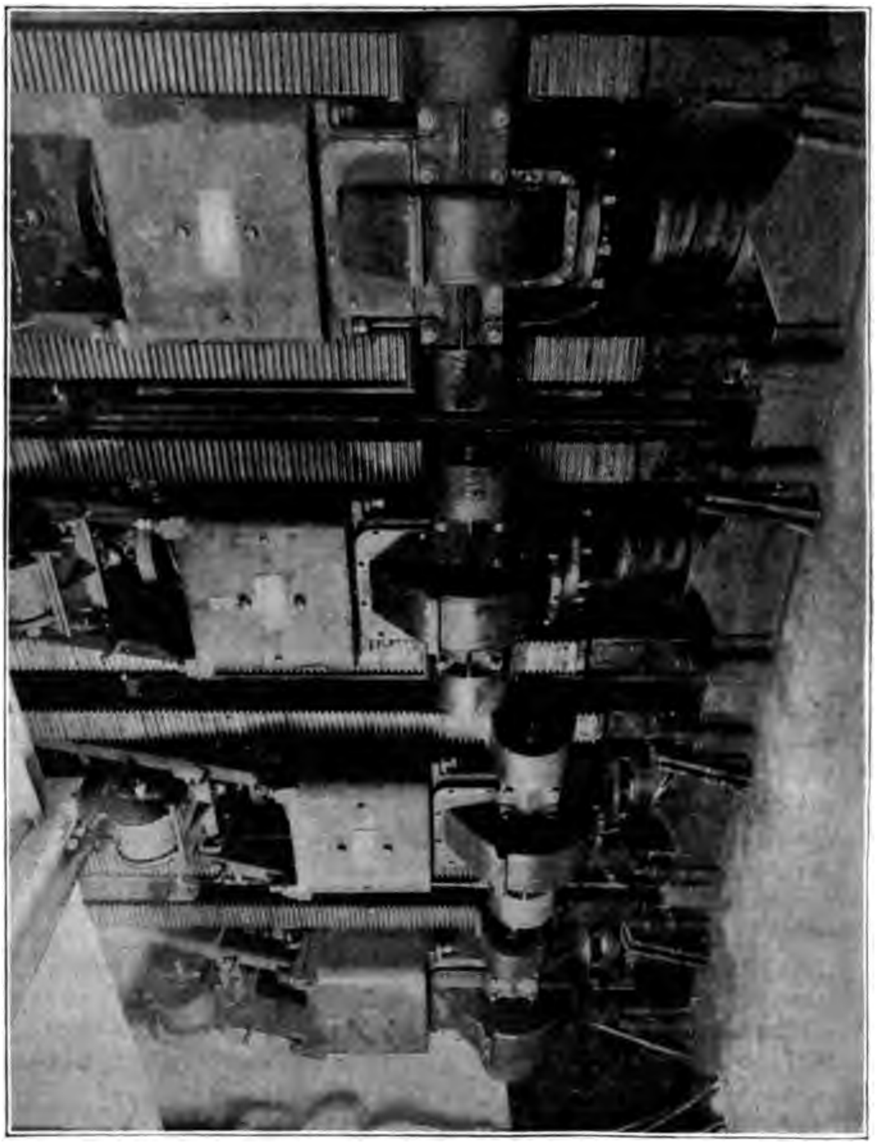
7 Fig. 3 gives an idea of the construction and design of the machine. The machine has a vertical armature and shaft, upon which are mounted, in order, the brake pulley, upper bearing, commutator, armature, coupling, worm, lower bearing, and roller thrust. The armature is keyed rigidly to the shaft and is connected to the worm, which is really a sleeve on the shaft, by means of the coupling shown. This is arranged so as to permit of the armature being rotated for the purpose of smoothing up the commutator, etc., without operating the gearing.

8 The worm drives the two worm wheels, which are mounted on the two horizontal shafts, and on these shafts are four pinions which engage the four vertical racks which in turn are mounted on cast iron columns, up and down which the motor operates.

9 The current is carried to the armature by trolleys mounted on porcelain blocks on the inner face of one of the beams. One set of the trolley brushes is shown in Fig. 3. They are made with a superabundance of wearing and contact surface, and after five years there are no burned spots on the trolley.

10 Fig. 4 shows the arrangement of the flexible cables which are put up in duplicate and carry the circuits for the fields brake *solenoid,* and slack cable device.

11 Fig. 5 shows the detail of the lower pneumatic buffer, the upper buffers are clearly shown in Fig. 3. These buffers are designed



with sufficient capacity to take care of the momentum of the machine when traveling at full speed, plus the full power of the motor.

12 The motor of this machine is specially designed. In the first machine it was armature controlled; in the last four, field controlled. The lower part of the machine (Fig. 3) is an oil chamber which is filled with oil to a point just below the horizontal shafts. All parts of the machine are automatically lubricated with the exception of the upper bearing and the idler; these are supplied with grease cups and require attention about once a week. This chamber being filled with oil, the rotation of the worm wheels and worm lubricate every part of it perfectly, including the bearings of the horizontal shafts. The first machine ran 2½ years on the first charge of oil without attention. The last four machines have now been in nearly two years without *changing* the oil, and the total bill of expense for lubrication is $6.

13 The service of this machine is shown by a test made on the first one, when doing regular business and running express, stopping at five out of nine floors. The car made 547 round trips in 540 minutes. The life of the cables is unusually long as shown by the record of the first machine. After five years service and making 25 000 car miles, they are still in good condition and it is the opinion of the inspectors that they are good for 50 per cent more service. The design and construction of this machine are such as to make it most reliable and durable and thus eliminate repairs. After 25 000 miles of car travel the racks have not worn out all the tools marks, and the teeth of the phosphor bronze worm wheels are hardly polished all the way across their face. The total bill for repairs for the four machines (Fig. 4) for one year was $318. This includes everything pertaining to the elevators. Of this amount only $83 was spent on the machine proper; $43 was spent for repairing an armature that was damaged by a wire band becoming loose at night, leaving $40 as the total repair bill on four machines for a year, or $10 per year per elevator, the balance being spent on the cars, signal gates, controllers, etc.

14 The great feature of this machine is its safety, which should be the first consideration in any elevator. Automatic stops are placed at both ends of travel of the machine which slow down the machine, cut off the current and set the brake, in case the operator fails to do so, and if the machine goes beyond this point it trips the main circuit breaker and cuts off the current from both controller and machine and beyond this again are the buffers, or mechanical stops, which are sufficient to take care of the machine in case the operator and all automatics fail. It is evident from this arrangement that the

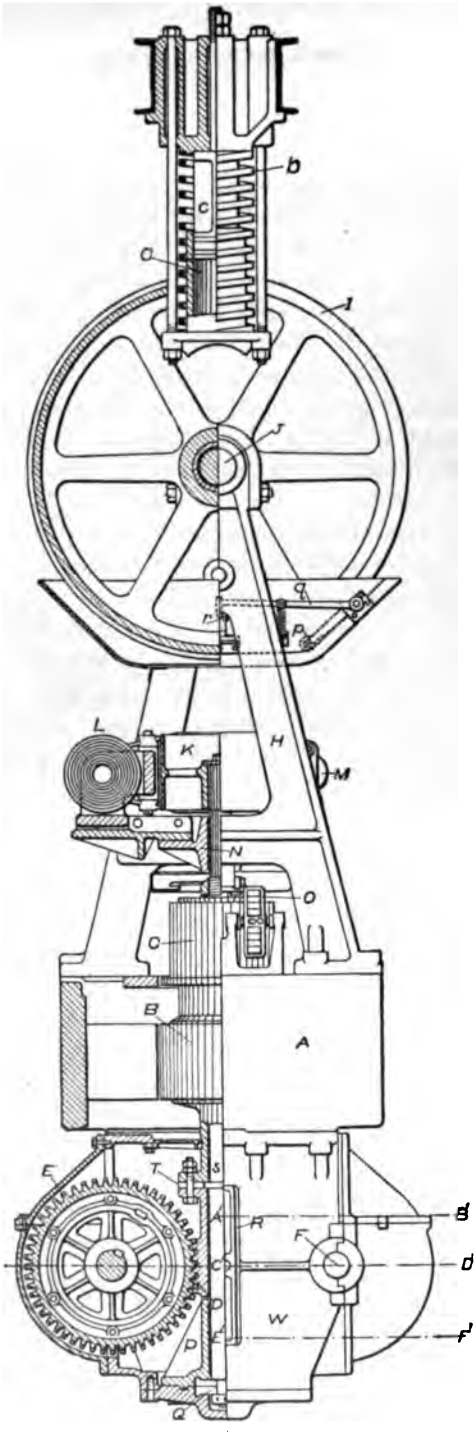


FIG. 3.—CENTRAL SECTION AND SIDE ELEVATION

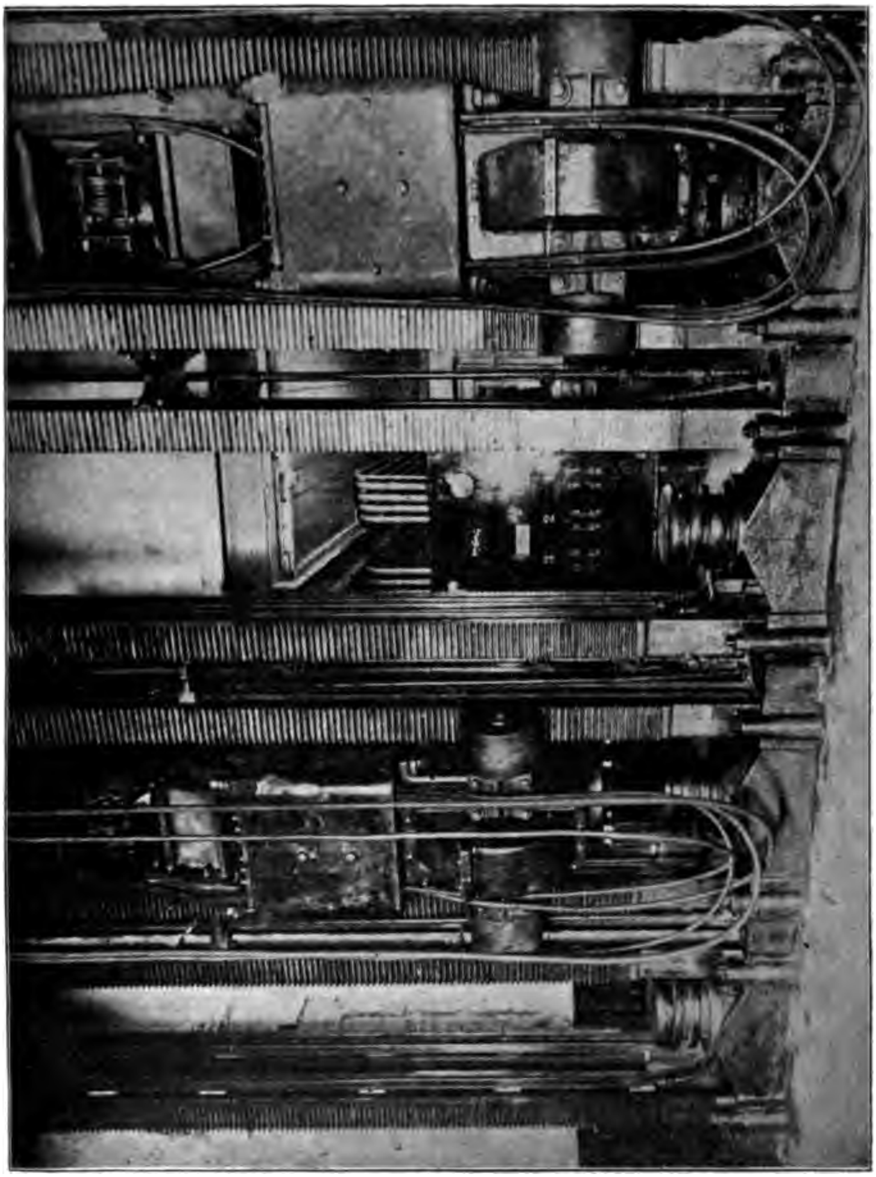


FIG. 4 VIEW SHOWING FLEXIBLE CABLES

car can never be jerked into the overhead work and pull the cables out of the car, as has often happened in other types of elevators; neither can it be dropped into the basement and the counter weights pulled down upon the car, a most common and serious accident in other elevators. A greater strain can never be put upon these cables than the load in the car. A push button is placed in the car whereby the main circuit breaker can be instantly tripped by the operator, shutting off the current from both the controller and machine. This is for use in case of disarrangement of the car box of the controller. This principle of the machine and these arrangements make it the safest electric elevator in existence. All the parts of these machines

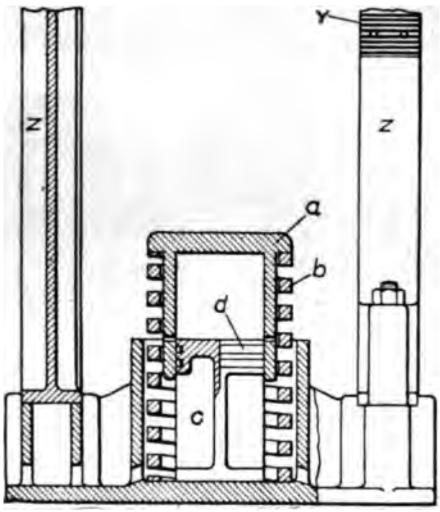


FIG. 5 BED PLATE AND LOWER BUFFER

are accessible when the machines are at the lower end of travel and are easily and quickly taken apart and put together.

15 I have recently made some improvements in the first machine, changing its old spring buffers to oil buffers, and I find the oil buffers are a decided improvement over the pneumatic, as they have a greater capacity and *no recoil*, the objectionable feature of the pneumatic buffer. The speed of the machines I have already installed, range from 540 to 600 feet per minute, but a much greater speed can be given, if desired, and safely controlled. In the case of very high office buildings, such as are being erected in New York I could safely give them a speed of a thousand feet per minute. This elevator is

particularly adapted for extremely high buildings, there being no additional complications in its construction or operation in the highest buildings over those of ordinary height. The operation and control of this elevator is pronounced by all who have ridden in it to be *ideal*, its start and stop being smooth and at the same time very quick, it being possible to reverse this car when traveling at full speed without a perceptible pause and without the slightest shock or jar. These features mean increased and satisfactory elevator service and make it particularly adapted for service where ladies are patrons.

16 The space occupied by these machines, including clearance is 52 by 42 inches, but I am working on a new design which will bring the width of this shaft down to 20 by 24 inches.

17 The racks and pinions are all cut steel and when they are properly cut and erected they run noiselessly. The most noise from these machines is the hum of the commutator.

18 The current consumption of the first machine, running express for a period of over four years was 3.44 kw. per car mile, there being conditions and days when it dropped below 3 kw. per car mile. The four machines shown in Fig. 2 which run locally operating much larger and heavier cars and carrying heavier loads showed an average current consumption for a period of 76 weeks of 3.5 kw. per car mile. As I said before, the service is unusual, and is undoubtedly the severest required of any elevators in this country.

Mr. E. S. Matthews Under this title Mr. Pratt invites our attention to an electric wheel and axle friction cable drive elevator which has been called the gearless traction electric elevator, and to a device which he advocates attaching thereto for the purpose of improving it generally and particularly for rendering it safer.

2 The friction cable drive has been well known in cable railway work, mining and blast furnace hoists, and, to a limited extent, in elevator work; but until recently it has not been extensively employed in high grade passenger elevator construction. There is, however, no reason why it should not be so employed under proper conditions.

3 It is interesting to note some of the earlier types of this friction drive elevator, and Fig. 1 shows a form of factory elevator machine driven by belt in which the friction cable drive was employed a quarter of a century ago, in exactly the same manner as in the traction elevator of today. This machine was usually located as shown in the sketch, in some story of the building (not over the hatchway, as is now usual with the traction elevator), and while the lifting end of the cables passed up the hatchway to the overhead sheaves, the coun-

terweight end, passing up through the floors of the factory near the hatchway (as shown), as this was not considered objectionable in factory construction.

4 Fig. 2 shows a sketch of a steam direct elevator machine which employed the friction cable drive in a little different form, utilizing about 270 degrees of arc contact, and this machine is particularly interesting at this time as it also employed a direct wheel and axle steam power drive, a steam dynamic brake and a steam releasing

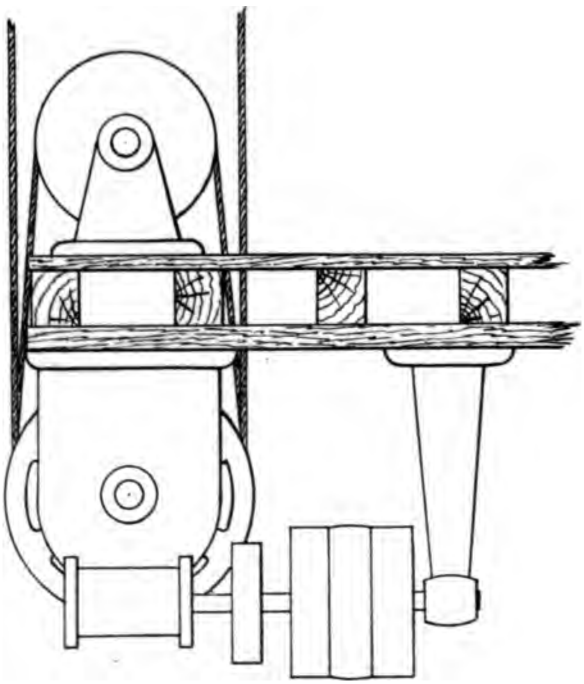


FIG. 1 THE FRICTION DRIVE OF 25 YEARS AGO

friction brake, or exactly the same power driving and controlling devices which are now employed on the gearless traction elevator with the mere substitution of the force of electricity for that of steam. This elevator was constructed by Henry J. Reedy, of Cincinnati, Ohio, a man of more than ordinary originality and ingenuity in mechanical contrivance and was successful in every respect except that the oscillating cylinder mechanism proved defective.

5 The Crane steam direct elevator employed the steam dynamic brake aided by the friction of the worm gear and the engine, in stopping and holding its load.

6 It is a marked peculiarity of the elevator industry that as soon as a new type of machine is brought prominently forward, many arguments are at once discovered in its favor, and they are strenuously advanced by its advocates possibly without mature consideration.

7 We have seen this in the case of the plunger elevator which we discussed about a year ago.

8 Paragraph 5 of Mr. Pratt's paper seems to the writer to be of this nature. It reads as follows:

"Experiments made by the author on this form of traction rope drive, using iron wire hoisting ropes running in smooth round grooves in the traction sheave, with from 1½ to 7½ half traction turns, demonstrate that the least traction obtained is with new dry ropes on new dry grooves, and that after considerable running there is not 5 per cent difference in traction between a dry rope and a rope flooded with any kind of lubrication. This establishes the fact that if this elevator will handle its full load when it is first started with new ropes, it will always handle its full load safely."

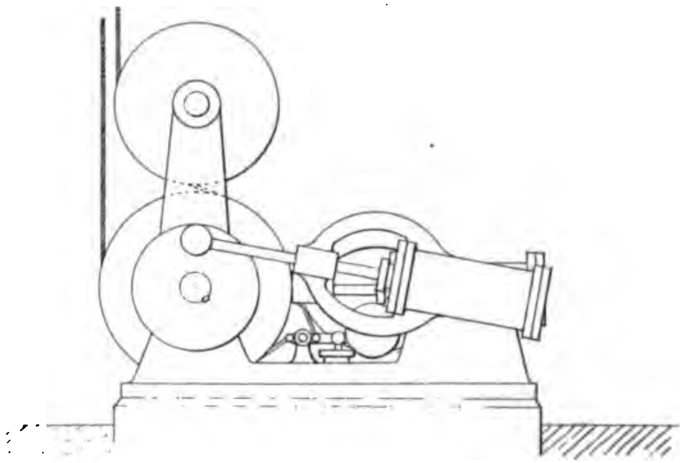


FIG. 2 REEDY STEAM DIRECT ELEVATOR

9 These experiments, if accurate, also seem to establish the fact that the coefficient of friction between metal surfaces dry and amply lubricated is practically the same, which conclusion is, of course, untenable.

10 Further, the results as stated do not agree with the experience of the writer or that of the Trenton Iron Company, as quoted in Kent's Handbook, or with well known determinations of the coefficient of friction.

11 The Trenton Iron Company gives for the coefficient of friction of wire rope on a grooved iron drum 0.120 when dry, and 0.070 when

greasy; and adds the statement that the importance of keeping the ropes dry is evident from these figures.

12 The manner in which the coefficient of friction enters into the determination of the pull of the friction cable drive or traction, as it is now called, is shown from the fundamental equations governing the case.

Let T_1 be the tension on the least pulled cables on one side of the driving sheave when slipping is about to take place.

Let T_2 be the tension on the most pulled cables on the other side of the driving sheave at the same time.

Let μ be the coefficient of friction.

Let θ be the angle of contact of cables over driving sheave in circular measure.

Then

$$\int_{T_1}^{T_2} \frac{dT}{T} = \mu \int_0^{\theta} d\theta \qquad [1]$$

or

$$hyp.\ log\ \frac{T_2}{T_1} = \mu\theta \qquad [2]$$

or

$$\frac{T_2}{T_1} = \varepsilon^{\mu\theta} \qquad [3]$$

when ε = the base of the system of natural logarithms.

13 We thus see that the coefficient of friction enters into the determination of the traction as an exponential function, thus strongly affecting the result.

14 It is sometimes stated that the rigidity of the wire cables is so great as to seriously modify the theoretical considerations above advanced, and at a superficial glance such might seem to be the case.

15 We will find, however, that under the conditions of the problem as it exists in practice, this rigidity has but slight effect and may be practically neglected.

Let M = the bending moment producing curvature around the driving sheave.

Let R = the radius of the driving sheave.

Let I = the moment of inertia of a single wire of the cable.

Let T = the tension applied to the wire to produce the curvature required.

Let E = the modulus of elasticity for wire in wire rope with the twist employed in this construction.

Let p = the pressure per unit length of arc required to produce the required curvature at the point where the curvature is a maximum.

Let n = the number of wires in the wire rope.

Then since $pR = T$, $p = \frac{T}{R}$ and $M = \frac{T}{2R}$ and remembering that $M = \frac{EI}{R}$ we have, examining a single wire,

$$\frac{T}{2R} = \frac{EI}{R} \qquad [4]$$

or in the case of a wire rope 0.75 inches in diameter, composed of wires of 0.05 inch diameter, where E is 15 000 000 a special value given by Rankine for use in wire rope computations, and which the writer considers practically correct we find T = 9.206 pounds. With wire rope 0.625 in diameter composed of wires 0.045 inch in diameter we find T = 6.039 pounds.

16 These ropes have six strands of 19 wires each, a total of 114 wires; we thus ascertain that when carrying loads of 1050 and 688 pounds respectively $\frac{3}{4}$ inch and $\frac{5}{8}$ inch wire cables will truly conform to the curvature of the driving sheave, and exercise upon it the proper pressure due to the tension upon them, except for a unit distance of arc as they leave the wheel where they become tangent to its circumference just that much earlier than a perfectly flexible band would do.

17 When thus operating the $\frac{3}{4}$ inch cable is working under a factor of safety of 18 and the $\frac{5}{8}$ inch cable under a factor of safety of 25.

18 With the 40 inch diameter driving sheave mentioned in Mr. Pratt's paper and the ordinary design, the variation of the angle θ is about 3 per cent from that taken by a perfectly flexible band and the variation of the angle θ between that caused by a fully loaded car and an empty car is about $\frac{1}{2}$ of 1 per cent.

19 Since the amount of this inoperative tangency varies inversely as the square root of the tension of the cables we see that their rigidity does not materially affect the laws governing the friction drive or traction of the machine.

20 The bending of these cables of course lowers the mechanical efficiency of the machine, but we are entirely familiar with this consideration and do not need to investigate it at this time.

21 It is interesting to determine the conditions under which the cable works to the best advantage or when a due proportion of stress is caused by bending and tension respectively dependent upon the relative diameters of the cable wires and the driving sheave.

Let f be the total stress and f_b and f_t the stress caused by bending and the tension respectively,

$$\text{then } f = f_b + f_t \qquad [5]$$

22 The bending moment is $M = \frac{EI}{R}$ and also $M = f_b \frac{I}{\frac{1}{2}\delta}$ when δ, is the diameter of the wire. Equating these values $f_b = \frac{E\delta}{2R}$. If T is the total longitudinal tension in the rope of n wires each of δ inches diameter, then $f_t = \frac{T}{\frac{\pi}{4}\delta^2 n}$, and the total stress of the most strained wires is $f = \frac{E\delta}{2R} + \frac{T}{\frac{\pi}{4}\delta^2 n}$ hence,

$$T = \left(f - \frac{\delta E}{2R}\right)\frac{\pi}{4}\delta^2 n \qquad [6]$$

23 Differentiating and placing $\frac{dT}{d\delta} = 0$ we find $\frac{R}{\delta} = \frac{3E}{4f}$ or $R = 375$.

24 If the wire is $\frac{1}{20}$ inch diameter the diameter of the driving sheave would be 37½ inches.

25 It has always been well known that the high speed electric elevator depends entirely upon friction for sustaining its load when at rest; but the extreme simplicity of the design of the traction elevator reduces this friction to merely that of a brake and it brings this fact out prominently.

26 Before a wreck could occur from the failure of this friction brake on the machine, the emergency car brake, and the car safety device would also both have to fail and simultaneous failure of all these three devices is highly improbable; while terminal buffers control anything safely at the limits of travel except the most extraordinary car velocities.

27 The machine would doubtless be improved by having, like a hydraulic elevator, a positive sustaining power; provided that dis-

advantages and complications are not introduced which more than offset any gain effected.

28 If all the good results, so fully mentioned by Mr. Pratt in his paper, are to be obtained by the use of his device, they can be demonstrated either by a sound and scientific mathematical treatment or by experiment and either way is equally conclusive for there is no conflict between true theory, worthy of the name, and experimental physics.

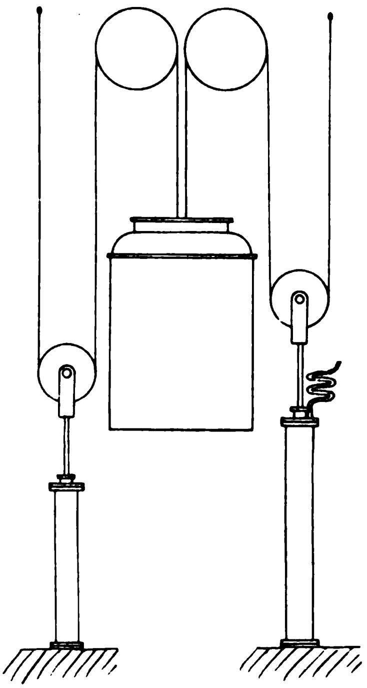


FIG. 3 SAFETY ELEVATOR DEMONSTRATED IN BROOKLYN

29 While the author has given us much valuable matter in this paper it seems to be largely made up of predictions of expected results based almost entirely on reasoning from analogy, which is never of itself logically conclusive.

30 Opinions on such subjects often vary and demonstration by experiment is the only method of convincing all sorts and kinds of persons.

31 The only question involved, it seems to the writer, is that of safety for it is totally unnecessary to add a second motor to the apparatus in order to secure proper control.

32 It hardly seems necessary to discuss the elevator brought to our attention by Mr. Mabbs for every engineer can judge of its comparative complexity, and the space taken up by the machine extending up through the building and which must always be accessible at all points is of itself alone prohibitive. The writer has never seen any elevator driven by a rack and pinion from Hanford's elevator years ago installed in the State House in Boston, Mass., and abandoned to the Mabbs elevator of today, in which the motion of the car is as smooth as he would wish in passenger elevator service.

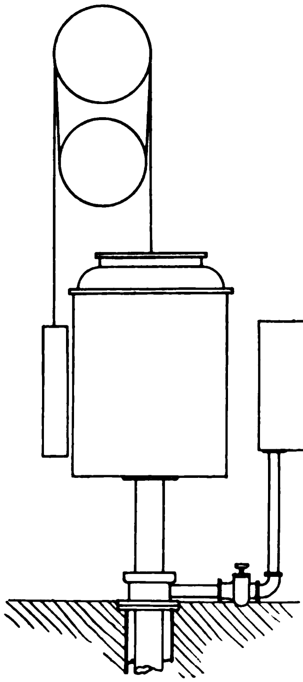


FIG. 4

TRACTION AND PLUNGER ELEVATOR RUNNING IN NEW YORK CITY

33 The writer does not feel that the gearless traction drive elevator "has all the elements of safety and perfection of control of the hydraulic elevator" for a passenger car on one end of a set of cables and a heavy over-balance weight on the other end, causing the elevator to possess the quality of possibly falling upwards as well as downwards, and with no sustaining power beyond a friction

brake, cannot, from the very nature of the case, be considered as inherently safe as the hydraulic elevator.

34 The principle of duplication seems to have been carried to excess of late in the invention of safety devices as an inspection of several lately offered will show.

35 Fig. 3 represents a device which was demonstrated by experimental apparatus before an audience in the city of Brooklyn, and consists practically in adding to any elevator a Hale 2 to 1 vertical cylinder machine carrying the counterweight within it and operating upon

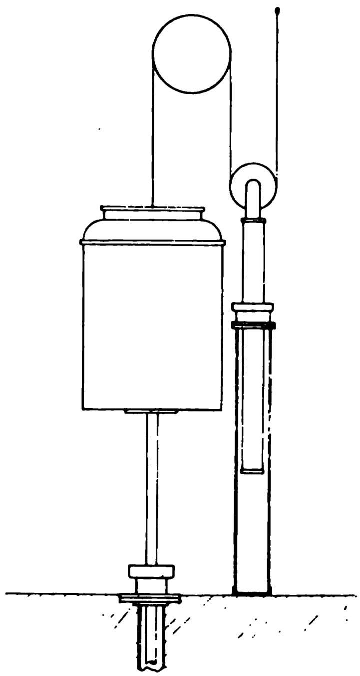


FIG. 5 ELEVATOR PROPOSED FOR METROPOLITAN TOWER

air which holds the car in case of falling by the compression caused by the resistance of its exit from this cylinder; this resistance being indicated in the sketch by the spiral coil of pipe above this cylinder.

36 Fig. 4 represents a gearless traction electric elevator with a plunger under the car which merely circulates the water to and from a supply tank for the sake of the safety supposed to be secured by such an operation as governed by the action of terminal stop valves operated by cables. It is in operation in a prominent building in New York City.

37 Fig. 5 represents the attachment to an ordinary plunger elevator of a Crane 2 to 1 gravity lifting plunger hydraulic elevator in the place of a counterweight in order that the mass of the counterweight may be controlled, that safe upward stops may be made on the plunger elevator, and the danger incident to pulling the car and plunger apart might be reduced to a minimum.

38 The writer is credibly informed that this construction was offered for the Metropolitan Life Insurance Co. Tower Building by advocates of the plunger elevator and it is evident in such a case that the Crane

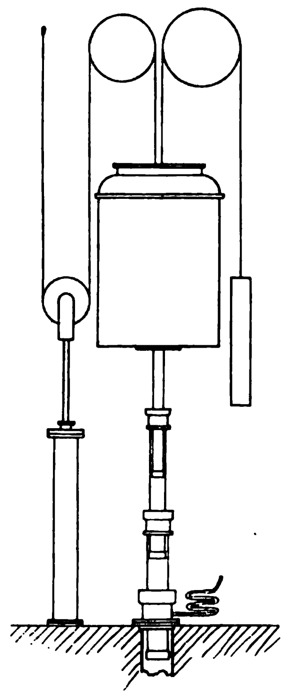


FIG. 6 TELESCOPIC ELEVATOR SAFETY

2 to 1 elevator replacing the counterweight would do all the lifting and controlling while the plunger would simply dangle from the car in order to give an appearance of safety, while to proceed one step further, it is evident that the construction would be much improved by amputation of the plunger as close to the car as possible, for every engineer now knows that in the case of the high rise plunger elevator the lifting is really done by the massive iron counterweight which raises the car when the lower portion of the plunger is buoyed up by water pressure.

39 Fig. 6 represents the placing of a telescopic plunger elevator under any elevator car, to be operated by air, and to act as a safety device on the same principle as that shown in Fig. 3, the resistance to air exit being shown by spiral pipe as in Fig. 3.

40 Fig. 7 represents an elevator demonstrated by experimental apparatus in Philadelphia and from which extraordinary design actual machines have been built, as the writer is credibly informed. It consists of two lifting plungers which raise the load by their weight and are operated by hydraulic pressure under them in addition to

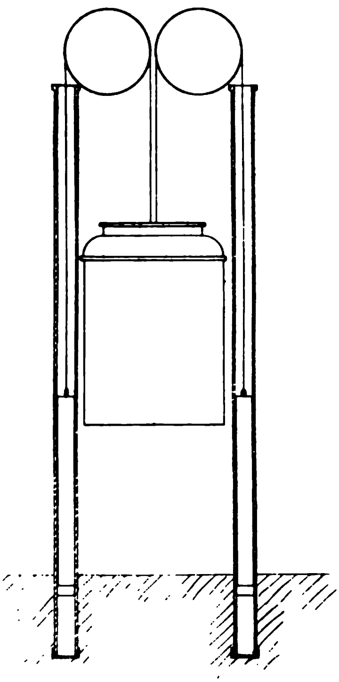


FIG. 7 AGGREGATION ELEVATOR ACTUALLY CONSTRUCTED

which an electric apparatus (not shown in the sketch) is attached to the overhead sheaves so that the car can be operated by this means also, or jointly by both. This device might justly be called the product of aggregation.

41 Fig. 8 represents the device offered by Mr. Pratt, which practically consists of adding a dead-lock worm gear elevator to the electric traction gearless elevator for the purpose of combining the advantages of these two machines.

42 Amid all this reduplication and aggregation, which cannot be called invention, we must not fail to remember that when we combine two or more elevator mechanisms we not only add their advantages but we also add their disadvantages, and that also incompatibility between some of the functions of these mechanisms may produce defects in the combination which neither of itself possessed.

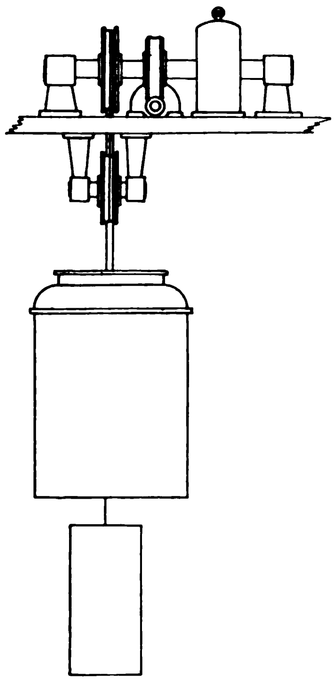


FIG. 8 THE PRATT DEVICE

43 The writer earnestly believes that better results will be obtained along the line of elevator progress by directing efforts in some other direction.

Mr. Thomas E. Brown The gearless traction drive elevator discussed by the author in his paper is, we believe, the best form of high speed electric passenger elevator yet devised. It has all the elements of safety and perfection of control of the hydraulic elevator, and is superior to it in that it maintains high acceleration and high speed with loads closely approaching the maximum.

2 This elevator was described by the writer in a paper read before the International Engineering Congress at St. Louis in 1904. In that

paper the writer said of it that it is "expected to be used generally in the future for high lifts and high speeds," and we think this expectation is rapidly being realized.

3 The machine in its principles is not new, the so called "traction drive" being that commonly used with cable railways, and used by the writer on several mountain railways. This form of drive was patented by Mr. George H. Reynolds in 1886, and the direct attachment of the motor to the driving sheave was shown by A. L. Duwelius in a patent issued in 1897, and the present machine is the combination of the direct motor of Duwelius with the "traction drive" of Reynolds.

4 Numbers of machines with friction rope drives have been in operation for years, both in this country and Europe, but in all, as far as the writer knows, high speed motors were used with reduction gearing, or non-retarding rigging, as covered by the Duwelius patents of the Otis Elevator Company, and the novelty of the present machine lies in the extremely slow speed of the motor and entire absence of gearing.

5 This combination was proposed by the writer several years ago, but met with no encouragement from electrical engineers, as it was believed that the slow speed motor would be extremely large and costly, and of very low efficiency.

6 Experience has shown, however, that when designed and constructed for this slow speed the efficiency is about as high as that of the high speed motors designed for elevator service, and high efficiency is maintained from about one-quarter to full load, or over nearly the whole range of loadings occurring in the variable elevator service.

7 The size and cost also are not prohibitive. The size of the motor is offset by the reduction in size of the drum, and the cost of the motor is offset to some extent by the saving in the gearing. The first cost of the elevator is greater than that of ordinary drum elevators, but when it is considered that the elevators now being constructed for the Metropolitan Life Tower will lift 3000 pounds in the car at a speed of 600 feet per minute, and will accelerate the total moving mass of about 20 000 pounds to this speed in about four seconds, it would seem doubtful whether a geared machine of the ordinary type to do the same duty could be produced at any less cost, and it is quite certain that any type of hydraulic machine of the same rise and duty would be much more expensive.

8 The writer thoroughly agrees with the author in the merits he describes as inherent in this type of machine. The sufficiency of the friction cable drive hardly admits of discussion, as it has been proved

by many years of use. The writer has installed a plant of three elevators having but 270 degrees of contact, and finds the tractive force sufficient for ordinary passenger elevator service.

9 We can not agree with the author that the traction is greatest with well worn and thoroughly lubricated ropes, as our own experiments indicate the contrary, but the difference between new dry, and old thoroughly lubricated ropes is less than 10 per cent; hence for all practical purposes the condition of the cables does not materially affect the traction.

10 The safety of the traction drive elevator is essentially greater than that of any other existing type for the following reasons:

a It admits of the use of a large number of ropes of which the simultaneous breakage is well nigh impossible, and may therefore be considered as entirely without danger of a "free fall."

b It is free from the greatest of all elevator dangers, namely, overwinding.

c It has the best of all speed regulators, namely, the shunt wound motor.

11 In addition to these points of safety inherent in the design and construction it is provided with:

a A double brake held off by the current, and only used in normal operation to hold the machine when not in motion.

b A speed governor controlling the motor.

c A hand brake in the car under the control of the operator.

d At least one set of efficient safety devices operated by a speed governor.

e Also the usual electric terminal stops, and in addition to these, long stroke buffers, under the car and counterweight, capable of stopping the elevator at the greatest speed it can reach, by gravity, at either terminal.

12 It would seem quite impossible that all of these safety elements could fail simultaneously; but let us assume for the sake of argument, that all the electric devices and the motor fail, and the two brakes on the machine fail, then under the worst condition which can occur in the cases cited by the author the car can accelerate by gravity at about 1.6 feet per second (one-twentieth of the acceleration of gravity); or the condition is the same as that of an ordinary trolley car on a 5 per cent grade.

13 We are perfectly content to ride in a trolley car with no other provision for safety, in the event of failure of the electric devices, than

brakes controlled by the motorman, and no efficient terminal stops at the bottom of the grade. Then how much more content we should be in an elevator car under the same conditions with all the automatic safeties noted in addition to the brakes, and most efficient terminal stops and buffers at the end of the run.

14 It would seem, therefore, that the worm gear and extra motor and control proposed by the author would be a complication added on the plea of safety to an already essentially safe machine, and tend to defeat the very objects of its production, namely, perfection of control, rapid service, simplicity and high efficiency.

15 The writer thinks there will be some practical difficulties in the design of the proposed worm gear. The author's patent shows the gear somewhat larger than the driving drum. If it were the same diameter as the driving drum, the normal peripheral speed of which must be 600 feet per minute, the pitch line speed of the worm of 5 degrees angle must be about 6700 feet per minute; rather a high speed, involving either a very large diameter of worm, or a very high motor speed.

16 Unless we are assured of absolute synchronism under all variations of acceleration and speed, a fast moving worm would be subjected to considerable frictional resistance, involving loss in efficiency, and the motor could not well be of negligible size, as it must be capable of overcoming the greatest pressure that may be brought upon the worm under any condition. It would seem that the acceleration and retardation of the high speed motor would tend to lengthen the starting and stopping distance of the elevator rather than shorten this distance, and detract from one of the greatest merits of the elevator, namely, active and rapid service.

17 It is difficult to see how the author's device can improve the almost uniform acceleration of 2.5 feet per second already accomplished by this machine.

18 There are many cases of two motors working together, but in all such cases where worms are used, they are of long pitch, and the motors do nearly equal work and synchronize mechanically. It would seem quite a different matter to synchronize two motors; one under variable loads, positive and negative, and the other under no load, and while the author suggests this, he does not give the slightest hint in his paper how it is to be accomplished.

19 It should also be considered whether such a device may not introduce elements of danger, such as the possibility of locking of the gears while in rapid motion and it is quite certain that a short-circuit of the motor would be destructive to the machine. The writer has

experienced the destruction of a double motor machine by the short-circuiting of one of the motors.

20 In the writer's opinion all the merits enumerated in Par. 22 of the paper exist in the elevator as it is now designed and constructed, and it will not be improved by the addition of the proposed worm gear device.

21 Mr. Matthews has given us a little outline of the history of the traction drive elevator, in which he showed us the machine n Fig. 2 which was produced by Mr. Reedy. Mr. George H. Reynolds in 1886, that is 22 years ago or at about the same time this one was produced, produced a traction drive elevator which is practically the same as that we use today, with the exception that instead of the motor driving the drum direct, it drove it through the medium of a worm gear; that is to say, it was essentially the same machine Mr. Pratt has shown us, if you remove the large motor and make the controlling motor do the driving.

22 The principal novelty of the traction elevator of today, is the attachment of the large slow speed motor direct on the axle without the intervention of any gearing.

23 Much stress has been laid by the other speakers on the question of safety. There can be no doubt that as high a degree of safety as can practically be obtained is essential in elevator service as well as in all means of transportation, but we must not forget that an elevator, like a locomotive, a steamboat, or a trolley car, has certain functions to perform, and while it must be made as reasonably safe as such service will permit, any attachment which you put upon it which cuts down that service, in other words impairs its usefulness for the purpose intended, certainly cannot be advantageous. Absolute safety can only be attained when motion is entirely prevented.

Mr. Clyde R. Place We have had the high speed elevator for a number of years, if 600 f.p.m. may be considered the limit of comfortable travel for persons riding in a car operated at that speed, but we have not had the high lift, high speed elevator with engines occupying so convenient a space as in the electric traction type, until very recently.

2 From personal observations and study of tests, it appears to the writer that the traction elevator has made possible almost an unlimited height of travel at a comfortable speed and a minimum electrical energy consumption, without sacrifice to control or comfort, while the question of safety is yet under discussion.

3 Theoretically, it would appear that Mr. Pratt has obtained a

very happy solution of a feature in electric elevator operation and construction, commanding the attention of all interested and concerned in this branch of engineering; practically, however, there exist certain features about the mechanical and electrical operation, as set forth by the author, which the writer would like to know are solved by regular elevator demonstration and operation before accepting the results to be obtained as set forth in the very complete presentation by the author.

4 Briefly, the author has taken the ordinary worm wheel and worm drum electric machine, decreased the size of the original driving motor to act as a controlling motor in place of the brake, and directly connected a large slow speed motor to the drum shaft and made the drum the traction sheave drive, so that some of the features inherent in the drum electric exist in the author's arrangement, while the spring-actuated brake, forming a mechanical feature, has been eliminated entirely. The resulting mechanism is a composite of the traction-electric and drum-gear electric of today. Whether or no this change is for the best in high-speed, high-lift electric-elevator operation is a question for demonstration and practical solution only.

5 There appear to the writer the following features:

a The control of the motors, the proper accelerations and retardations of the motors, and the tested assurance of their mutual and ready operation under the general conditions of elevator service.

b The proper design of the worm wheel and worm to accomplish comfortable operation of the car and to care for the safety of the elevator equipment and persons in case of some unusual occurrence to the motors or connections.

6 In regard to the first feature, two different elements under one car control are introduced: one, a large slow speed motor, quickly accelerated; the other, a small high speed motor slowly accelerated, both motors having different windings.

7 The question arises whether these two motors can be built, without an unusual amount of testing and adjustment, to operate so mutually that neither will momentarily assume the load function of the other. From the proposed design and operation, it can readily be seen that this condition should not be allowed to exist too frequently for good elevator operation.

8 The fact that a limited amount of work can be put into the traction sheave by the controlling motor before it is stopped by the overload does not signify that the driving motor can be allowed to work back through the worm wheel and worm. This being the case,

it would seem necessary to arrange the operation of the controlling motor a little in advance of the driving motor in order to insure that the controlling motor takes care of the acceleration and retardation of the car; only this motor is allowed to accomplish these operations, since it is manifest that the construction will not permit this of the other motor. Experiment and demonstration, however, may make it possible to adjust the starting, running and stopping of these motors so as to meet these severe requirements in elevator operation.

9 The second feature, that of the worm wheel and worm design for comfortable operation and safety, brings forward this point

10 It would appear that the angle of the worm should be considered with the speed of car travel and its average load. While, as the author states, certain angles prevent the worm wheel from driving the worm, other angles allow this action and it does not seem advisable to the writer to construct a worm which cannot be driven to a limited extent, by the driving motor or gravity load.

11 It is noted that the author speaks of the car "gradually" coming to a stop. This action depends upon the load in the car, its speed and the angle of the worm. These conditions being right, the car will come to a stop "gradually," otherwise not.

12 For example, suppose a car with average load is descending 600 f.p.m. and the controlling motor gets out of order or refuses to do its work in operating the worm, and the angle of the worm is too small for the driving motor or car to drive the worm, what would be the result? The car would be brought to such a sudden stop that not only would the persons in the car be injured but quite likely serious damage to the elevator equipment would result. On the other hand, if the angle of the worm was such as to allow it to be driven by the large motor or car, the car would accelerate in its descent and run away, producing unfavorable results, unless the car safeties were called into action. The question therefore arises,—What is the proper angle for the worm, and can this be definitely determined to meet the conditions likely to arise as noted? It seems to the writer that this question of the correct angle for the worm requires considerable thought, study and demonstration. Either a heavy balance wheel on the shaft of the worm to store sufficient energy might be considered in order to continue the rotation of the worm for a short space of time in the case where the worm cannot be driven by the car, or a small friction brake might be placed on this shaft to act in the case where the worm can be easily driven by the car, but the writer merely suggests these alternates.

13 The Electric Traction type of engine readily adapts itself to many advantageous conditions. It can be placed at the bottom or at the top of the elevator shaftway, as well as at intermediate floors, by a simple rearrangement of the idler sheave. The floor space occupied by the engine is small, and with its compact construction makes it specially adapted for high office building work, as the engine can be placed over the shaftway, and permits more rentable area in the building. This feature is brought out clearly in the elevator layout at No. 1 Wall Street, New York.

14 One of the buildings connected with the Grand Central Terminal Improvements is so constructed and situated that this type of engine has been considered for this building. The building has no basement, this space being occupied by tracks, but has a pipe loft for machinery between the third and fourth office floors while the design is arranged so that the building may be increased in height.

15 The writer anticipates a steadily growing field for the Electric Traction Elevator.

MR. C. W. NAYLOR[1] The ordinary worm gear drum type of electric machine has several serious defects, even sources of danger.

2 The brake wheel is too small in diameter; the brake, when electric, either for set or release is too sudden and will pull lifting cables out of clevises in two years or less; besides it makes too sudden a stop with all the disagreeable accompaniments, in spite of the fact that it is supposed to be arranged to go into action at some proper moment that will avoid the occurrence of that fault.

3 In practice it is impossible to adjust such a brake so that it will set alike for different speeds, loads, and temperatures in the machine.

4 The complicated wiring in both field and armature for a magnet control machine is a source of worry and confusion to the care taker and is sometimes carried to such an extreme that it is not absolutely certain in which direction a car is going to travel when the controller handle is thrown from the central or neutral position.

5 A cross, or a ground, or a short circuit, anywhere in the wiring will often lead to serious and not easily understood complications and uncertainty as to just what the machine is going to do when started.

6 This type of machine is limited to lifts of 200 feet or less, although there are fairly successful installations with somewhat longer lifts. It is not suited for speeds of over 350 or 400 feet per minute.

[1] Chief Engineer, Marshall Field, Chicago.

7 If the starting acceleration is not too great the machine can be very economical of current if properly counter-balanced.

8 In regard to the overhead traction machine to be used in your Singer building Mr. Pratt's suggestion for an auxiliary motor driven worm in place of the brake band is not so clear to the reader but that he might ask *will it synchronize with* the main motor. I am curious to know just how the system would work out in practice.

9 Is it not an attempt to get back to the worm gear drive on the elimination of which we have been congratulating ourselves?

10 The clanking pendant balance chains must be eliminated from the high lift and high speed elevator, from the open hatchway at least if not for good.

11 The quick setting car dog must also be relegated to the scrap pile.

Mr. R. P. Bolton The electrical traction elevator, to which this paper directs attention, is the logical outcome of a process of inventive deductions which has gradually brought together the simple elements of a slow-running motor, and a four-bend cable drive of sufficient surface and number of ropes to insure a frictional hold under starting resistances. The course of invention, in order to reach this simple result, has had to pass through various stages of complication, each of which introduced into the electrical method of operation some disadvantageous or insecure elements.

2 The ingenious screw-and-ball nut machine, designed by the author of this paper, was an attempt to attain high speed by imitating the operation of the expanding sheave motion of the hydraulic piston or ram, while the drum machine, which has become so very widely used for moderate speeds, is an adaptation of the high speed motor to the winding drum, by the intermediary of a reducing gear, generally in the form of a worm and wheel. These were followed by several forms of friction drives, highly ingenious but dubious, and all appear to have assumed, as a fixedly determined element, a high rotative speed of the electrical motor.

3 The author scarcely gives himself sufficient credit for his own share in directing the course of this now important development of electrical operation, for it was his experiments, to which he so briefly refers, which first made it clear that such a method of hoisting could be not only practically accomplished but successfully controlled at high speeds.

4 But the development of this method of operation, combined with the slow running motor lay dormant for some years, awaiting

the introduction to it of the means of positive arrest of its unlimited motion of car and counterbalance. To Mr. Thos. E. Brown the credit is due for the perception of the necessity, and for its offspring in the form of the hydraulic buffer attached to car and counterbalance.

5 The combination presents the elements of security to a superior degree. The ever present danger with the drum type of over running the car or the counterweight into the head beams and the equally present danger of misplaced ropes are eliminated, as well as the complicative double sets of counterweights, ropes and sheaves for the back drum and the car counter-balances.

6 The machine thus developed bears some general likeness to the hydraulic plunger machine, with the essential difference, however, that its moving mass is of less amount, and its balance of parts equal at all parts of its travel. Thus far we find the author in full sympathy with the development, but in Par. 11, he confronts us with an apparent course of hidden dangers, for which he proposes a device as a remedy.

7 The fact that a friction brake is not positive in its action is incontrovertible, but to a considerable extent that very element is conducive to a secure operation of the elevator. Any means of arresting the moving mass in an elevator, must be so regulated as to bring about a gradual retardation, otherwise the arrest, brought about with a positive appliance such as that which is proposed by the author, may introduce extreme strains into the working appliances. Stoppages of a sudden nature, it may well be remembered, are productive of the same effects upon the living load as a fall in one direction, or as involuntary ascent in the other direction.

8 The instantaneous arrest of a car descending at a speed of 960 feet per minute produces the same effect upon the passenger as a free fall to the ground of four feet, and the sudden stoppage of a car at the same speed in ascending, would leave the passengers to continue their travel and return to the car floor by gravity.

9 Any rigid appliance for arrest, therefore, requires careful provision for its relief in case of too sudden an application, as is done in the hydraulic machine, where the cutting off of the exit of water would otherwise result in an instantaneous and positive stoppage were it not for the usual relief valve.

10 It is probable therefore, that the synchronous worm and wheel device, to the merits of which the rest of this paper is devoted may eventually be found to be necessarily connected to the hoisting shaft by some means affording flexibility, whereby in case of its too

sudden stoppage of the moving mass, a certain relief motion may be permitted. Otherwise entire dependence for security of the elevator will be transferred from the electrical controlled valve to the electrical control of the secondary motor, which appears to be merely an exchange of liabilities.

11 It will be very interesting to learn the results of the author's experiments with this method of control in actual practice. Until this demonstration it will be well to withhold final judgment upon the frictional brake, which, as at present applied to this type of machine is a well tried apparatus, which, with the particular care by which it and all other parts of high class passenger elevators are attended, is not to be considered as entirely lacking in the element of safety. Further, the frictional brake, in its later development in the traction machine, is supplemented by electrical control of the powerful torque of the motor.

12 The brake operation being preceded by the gradual cutting out of the motive circuit, and by the stoppage of the motor by short circuiting the armature, it does not follow therefore that the frictional brake has in stopping the moving mass any severe duty to perform. As regards the reverse or starting operation, the inter-related operation of applying current to the motor and to the solenoid which pulls off the brake, is facilitated by the gradual cutting in of current in the armature circuit, and is not, as would appear from the author's remarks, a sudden full starting current applied to the armature prior to the release of the brake.

13 I think it would be well if a definition could be made of the term safety. It is evidently in itself lacking in comprehensiveness, since we find various adjectives utilized to express its relative character, such as "entire," "complete," "absolute," and, in the author's last words of the paper "perfect safety."

14 I regard the condition under which elevator apparatus should be found as better described by the word "security." The difference may perhaps be illustrated by the practice of bankers, who may feel considerable "safety" in loaning to certain persons, but are nevertheless customarily cautious enough to demand "security" in addition to safety.

15 In Par. 17, the writer used the phrase so constantly misused and productive of so much misunderstanding on the part of non-technical persons, in alleging that the car deprived of coöperation between motor and brake, "falls free" to the bottom of the hoistway. Such a term could be applicable only to such conditions as the entire separation from the car from all its supporting, or retarding,

or "safety" appliances. In this case, it is particularly misleading, since with this particular form of machine, the power of motor-control and reversal would still remain in the hands of the operator, while the descent of the car even under such conditions as described, would not be "free," being retarded by the inertia of the counterweight, ropes, rotating sheaves and rotor, to say nothing of the Pratt or other "safety" speed-controlling devices with which we may assume it to be equipped.

16 The author's point of view of the traction machine seems to be mainly that which deals with its powers of retardation of the moving material, and he has not dwelt so appreciatively as he might upon the feature of the important powers of acceleration which this type of machine affords, due to the large size of the motor, and to the elimination of much of the frictional resistance of operating parts.

17 The same features afford a capacity for the operation of maximum loads at maximum speeds and the combined result is the most effective element in the direction of traffic capacity, affecting beneficially the time consumption on the lifting side of the operation of elevator travel.

18 It is interesting, though a little amusing, to learn of the elaborate preparation taken prior to deciding upon this, the only practicable form of machine, for the tower portion of the Metropolitan building. One may be pardoned for wondering why it was necessary to take "over 1500 pages of testimony" regarding a matter in which elementary knowledge of elevator conditions must have eliminated practically every debatable element.

19 We do not learn if the same extent of attention was paid in the Singer building to this subject when the same decision was priorily reached, nor are we told whether the far more important matter of the extent and character of the elevator service to be provided in the case of either building, not merely by the machines, but by the cars, travels, floors and work which have been connected with them, received any attention at all.

20 It is, however, asserted that time was actually consumed in the consideration of direct plunger machines for the installation first referred to above, and presumably this subject forms some part of the fifteen hundred pages of testimony which could well have been spared. The position occupied by the passengers in such an apparatus would be comparable to the traditional fly upon the flywheel, without the ability, however, of the fly, to utilize wings in case of necessity.

21 With a loaded car at top of such a run, upwards of 350 feet of

plunger would be hanging from the bottom of the car, and the living load would form but about 5 per cent of the total mass in motion.

22 The published accounts of one of the tower buildings afford some information as to what number of elevators are to be installed therein and under what circumstances their duty is to be performed. Running express to the thirteenth floor above the ground floor, the elevators are to become way cars for from 22 to 28 floors above that point, a number of floors which general practice has shown to be excessive, even when locally served without the delay of the express run.

23 Moreover the convenient operation of a bank of cars of which one is extended considerably in travel beyond the others, results in delaying the time service of all. For so long a run, the cars which are described as being 25 square feet in area, are inadequate in size, and have insufficient margin of capacity to handle the minimum rate of traffic.

24 I figure that, with a sacrifice of but one per cent of the net rentable area, an adequate number of elevators could have been installed in the Singer tower, the result of which would have been to place the average service of the tower portion, ten floors nearer the street, a result which an authority in mortgage values tells me, would add several hundred thousand dollars to the real estate value of the property.

25 The speed of 600 feet per minute, which it is stated is demanded for these machines, is, by the circumstances of the service to which they are to be applied, of small relative value, since the service imposed upon them calls for local stops of such frequency that the maximum speed can be developed advantageously only on the comparatively short express run.

26 The superior power of the traction type of machine to accelerate maximum loads is the saving element in the adverse conditions of service to which they are to be applied.

27 With due allowance for this element it can be shown that to extract the entire tenants from the tower in case of panic or other necessity, about 40 minutes time would be required, whereas, with a properly proportioned service the same could be effected in 18½ minutes.

28 This is, I consider, a test which should be applied to the sufficiency of any elevator installation.

29 It is unfortunate that the opportunity, afforded by these high towers, of demonstrating the real capabilities of modern elevators, seems to have been so far missed, as to leave the subject very much

where it has been left by other new types of building, in a very tangled and indefinite condition, and the very elaborations devoted to the decisions on the subject of the type of elevator machine, however proper the conclusions thereby attained, may contribute to very indeterminate conclusions as regards the practicable value of tower buildings, which with proper provisions, as to the service to which these machines are to be applied, might take on a different complexion.

30 I am shortly to publish the results of my work on this part of the subject of elevators, and shall hope to have an opportunity at a later date of explaining to our members the limitations and operating conditions of elevators and their due and proportionate relations to the building which they serve.

MR. G. A. ORROK The author is to be congratulated on the ingenious and efficient means he uses to supersede the spring actuated friction brake, thus increasing the safety and reliability of the traction elevator machine.

2 Elevator accidents, while comparatively few, are yet common enough to make us welcome any improvements tending to greater safety, better control and reliability. The drum type of elevator machine, under the influence of the ever increasing height of our modern office building and the necessity of maintaining a comparatively high speed of car travel, has developed limitations and is given place in later installations to the traction type as the best machine for electric elevator service.

3 Many people have believed that the surest way to have safe elevators was to install the plunger type, putting up with the increased cost of operation to secure the appearance of safety which the presence of the plunger affords. This is a fairly good proposition when there is a steam plant of some size in the building, but with the power service of the building furnished electrically from a central station, now the usual practice, the electric pump and hydraulic elevator is at a decided disadvantage as compared with the electric elevator.

4 The introduction of the traction elevator is such a step in advance of the drum type that it will be used more often for high speed work than any other. But what about existing plants with plunger elevators whose owners have to maintain a steam plant or use electric pumps, in either case not getting the economy which they should obtain? This type of elevator is mainly chosen on account of its safety in operation and when installed, is not being replaced by other types. For such cases as these a Member of the Society, Mr. Thos. E. Murray, has devised a combination of the two types, putting a traction

machine on the counterweight rope of the existing plunger elevator, taking off the hydraulic hand control and substituting a tank for the pressure water supply, leaving of the hydraulic arrangements only the automatic top and bottom stops. The plunger elevator now becomes an electrically driven traction elevator with a plunger

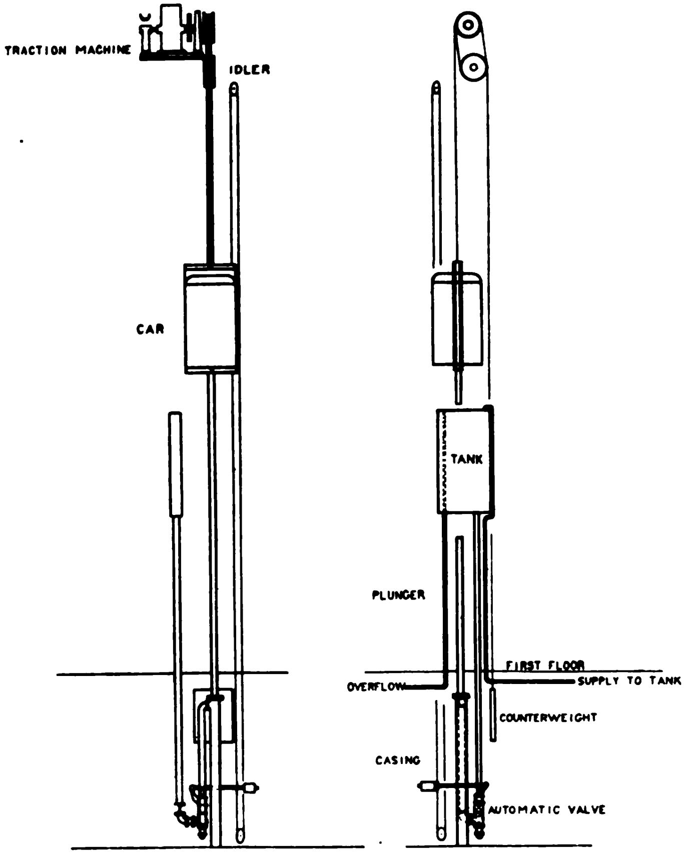


FIG. 1 COMBINED TRACTION AND PLUNGER ELEVATOR

safety; is safe to a greater degree than the plunger, and is also fairly efficient. Fig. 1 shows the arrangement of the experimental machine as at present installed in the office building of The New York Edison Company.

5 The elevator, as outlined above, consists of a car suspended from cables which pass over and partly around the sheaves of an ordinary

traction machine, a counterweight being attached to the opposite ends of the cable.

6 The car is also equipped with a plunger running in a casing which is connected to a water supply of practically constant head. The car is operated by an electric control, in the same manner as a traction machine, and brought to rest by an electrically controlled brake. Two automatic valves are placed between the casing and

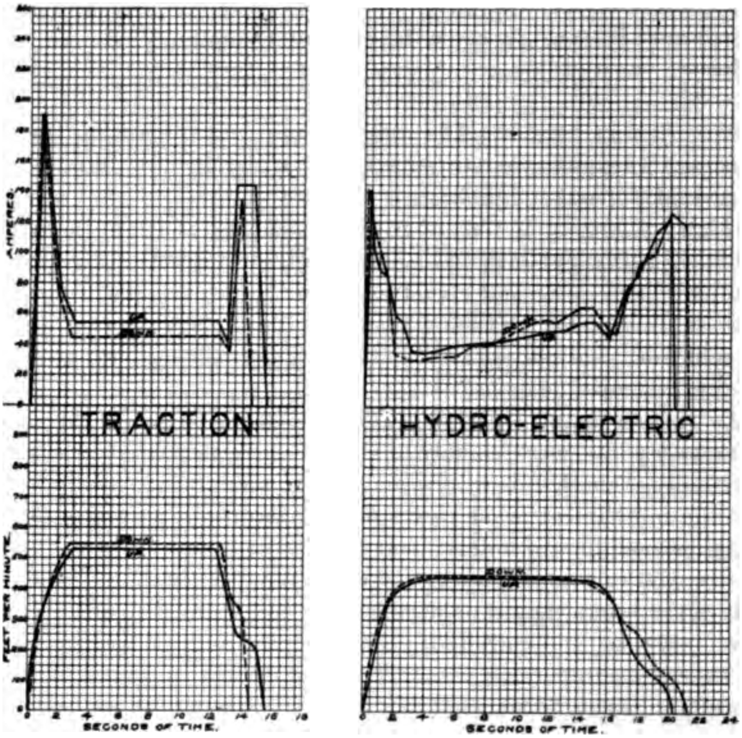


FIG. 2 SPEED AND ENERGY CURVES FOR TRACTION AND HYDRO-ELECTRIC TYPES

water supply—one being automatically operated when the car reaches a point at a certain distance from the bottom floor and the other when the car arrives at a certain distance from the top floor.

7 We have at the Duane Street building a traction elevator which is run under similar conditions with the hydro-electric elevator, as this combination may be called. The travel of the car in both cases is about 120 feet, while the speed of the hydro-electric elevator is approximately 450 feet per minute, and of the traction elevator

approximately 550 feet per minute. We have made tests of both elevators under approximately equal conditions of service, and Fig. 2 shows curves of energy and speed covering both tests.

8 The curve of the hydro-electric elevator shows a large area for the braking current at the end of the run which is now being reduced by the application of other devices. The total current used per car mile in the case of the hydro-electric elevator under these conditions is 3.6 kilowatts per car mile; the current used for the traction elevator is 3.3 kilowatts per car mile. It should be noted that with better speed and higher lift these figures would undoubtedly be much reduced.

Mr. John D. Ihlder The writer agrees with the author that the gearless 1:1 traction elevator as it has been installed for the past years in several important buildings is the best elevator so far designed for high buildings. In the design of this machine, as the author points out, the parts are reduced to a minimum, so that with proper design of motor, controller and structural work the elevator will not only operate at a higher efficiency than any other elevator used for this class of work, but also is safer, and having few parts subject to deterioration its repair expense is very small.

2 The mechanical brake (the only feature to which the author takes exception) may possibly in the future be improved, just as undoubtedly other details will be modified to meet future requirements, but the mechanical brake in its present form is a very safe device. It is designed in two independent halves, each with sufficient power to stop the car, so that even under the remote possibility that one-half of the brake should be disabled, the other half will still insure a safe operation; and considering that the elevator can be handled by an experienced operator without the use of the mechanical brake there is no reason to fear that any failure on the part of the brake can endanger the safe operation of the elevator.

3 Before advising, therefore, any substitution for the brake, we must carefully consider whether the proposed change really constitutes an improvement. To be an improvement the change should either give a better mechanical design, a simpler operation, or add to the safety. Neither of these requirements are filled by the author's proposition.

4 The non-reversible gear and control motor as a substitute for the mechanical brake add a number of parts to the present simple machine, making it more complicated and expensive.

5 The operation of the control motor is far from the simple prob-

lem which the author leads us to believe. He dismisses this problem with the statement to connect up the controlling motor in circuit with "the hoisting motor so they will synchronize with each other in starting, stopping and speed regulation."

6 If the author should attempt to construct a machine as proposed he will find that to make a control motor fill these conditions, and in addition operate in conjunction with a device to properly control the power supply to the hoisting motor is a very difficult problem, not merely a practical combination of standard elevator construction requiring no experiment. The writer's opinion is that he will become discouraged before he gets a practical solution.

7 If a practical solution can be solved it will be very complicated, consuming a great deal more power than the small power used for the operation of the mechanical brake, since in addition to the power required to run the control motor considerable power will be wasted in friction on the non-reversible gear, which must retard either the control motor or the hoisting motor, whichever happens to be the faster during the different operations of starting, running, stopping and speed regulation.

8 Considering the point of safety, a non-reversible gear will undoubtedly prevent the hoisting motor from running faster than the speed of the control motor allows; but in case the control motor should become short-circuited, causing it to stop short, the hoisting motor would also be arrested so suddenly that it might become dangerous to the passengers and the machine.

9 The device is thus open to objection on all points where it should show an advantage over the mechanical brake, and it does not seem worth further serious consideration until the author can show on a completed machine that the objections raised are unfounded.

MR. F. T. ELLITHORPE[1] The introduction of elevators has stimulated inventors to patent a large number of safety devices. Some of these possess considerable merit, while many are practically worthless.

2 The accounts of elevator accidents from the published data which the speaker has gathered for many years is alarming, and a large majority of them are caused by the elevator operator not properly closing the elevator doors.

3 During the past year from this feature of elevator accidents the number ran up to about 750, this being a ratio of nearly 9 to 1, occur-

[1] Engineer, New York.

ring from this direction, as against all other accidents happening from other causes on the vertical railroad.

4 Inventors have not given due attention to the providing of devices that properly safe-guard elevator doors.

5 Would it not be wise to have a device that would act properly so as not to retard the speed of the elevator, and yet produce more protection to the passengers?

6 You are probably aware that there are several devices on the market which have not been entirely satisfactory; most of them seriously retard the speed of the elevator. What seems necessary is a device which will cause the operator to be more careful in the closing of the elevator doors. With this properly done, the accident lists in the future must be greatly decreased.

THE AUTHOR To all discussions both for and against this control, the author concedes that there are several predictions requiring means not shown in his paper. The rigidity of the direct gearing was undesirable for the best results; and the author has provided means whereby the speed of the controlling motor positively regulates the speed of the main motor by means of differential gearing interposed between the worm gear and the main motor, whereby the power that drives or retards the main motor is regulated to compel it to synchronize with the controlling motor, the control remaining *positive but flexible to a limited extent.* This method realizes all the predictions made of efficiency and control as well as safety, but will be subject to another paper referring to its application to speed control of all types of power units.

2 It is fortunate for the author that the criticisms have been destructive rather than constructive, otherwise some fortunate critic might have deprived him of his discovery of a new and valuable speed control. But whether the author or the critic achieves the result, the utility of presenting and discussing advanced ideas before our Society is demonstrated in this instance. This closure will show how the safety functions can be obtained in a perfectly simple and reliable way, with no possible interference with the present functions of this elevator, and with no material loss in efficiency:

3 The author's efforts to introduce this present method of traction rope drive have been, namely,

1891 Designed one for a 1000-foot tower, intended for the Chicago World's Fair, but not erected.

1896 Advised it for the Park Row Building, New York.

1899 Paper on "Elevators," in Transactions, vol. 20, p. 826.

1899 Advised the Otis Elevator Company to use it.

1902 Built one for the Marine Engine and Machine Company.

4 While there is some satisfaction in anticipating by over 14 years, a method so obvious that it should have been accepted at the first suggestion, it is not so satisfactory to see history repeat itself by rejecting another suggestion equally obvious, important and logical.

5 There are members of our Society and other engineers who will read this paper, who know that this new traction elevator has low-

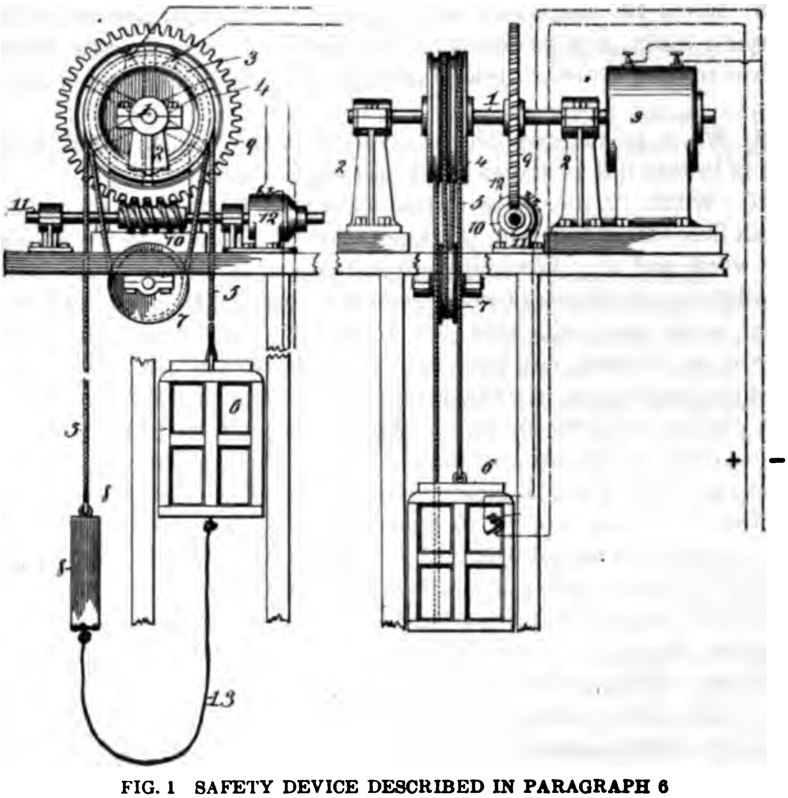


FIG. 1 SAFETY DEVICE DESCRIBED IN PARAGRAPH 6

ered the old standard of safety, and who are in a position to have this grave error rectified. To such engineers I present the following statement of one way in which this elevator can be *positively controlled*.

6 The control as originally presented has its distinct function of a continuous safety brake always engaged, and as such is a practically operative mechanism. Referring to Fig. 1: *1* Main armature shaft.

2 Bearings for main armature shaft. *3* Main hoisting motor, about 50 horse power. *4* Traction driving sheave. *5* Hoisting ropes. *6* Elevator car. *7* Idler sheave. *8* Counterweight. *9* Low pitch worm gear. *10* Low pitch worm. *11* Worm shaft and armature shaft of motor. *12* Controlling motor, one to five horse power. *13* Tail ropes or chains, to compensate for variable effect of ropes *5*.

7 Motor *3*, shunt wound, speed variation not over 10 per cent with varying loads acts as motor to hoist and as generator to lower. About 50 horse power at 60 revolutions per minute.

8 Motor *12*, compound wound, speed variation 20 per cent with varying loads, acts as motor all the time. Uses about one horse power to drive worm *10* practically free at 1200 revolutions per minute.

9 Worm gear *9*, one-half the diameter of traction sheave *4*, teeth cut in bronze ring bolted to flange cast on sheave *4*.

10 Worm *10*, double thread 3 inches lead, 6 inches diameter at pitch line, thrust taken on friction washers 7 inches diameter, casing for worm and gear keeping worm submerged in oil as usual; 1200 revolutions per minute of worm follows the car at 600 feet per minute. This worm gear will hold ten times the maximum net load. The angle of worm and the ring friction thrust washers can be such that the gear cannot *start* the worm in motion from a point of rest, but can *continue* to drive the worm, either *slightly accelerating* its speed, or be more or less *retarded* in speed by the worm's friction, and it transmits only about 1 horse power but is of the same dimensions and speed generally used to transmit up to 25 horse power. It will show no material wear in 100 years, and always run cool. This worm in tandem gear, or single worm with roller thrust, could be driven by its gear, but not if it thrusts against friction ring washers 7 inches diameter. Nor will this introduced friction (the seven inch washers) add to the load of the controlling motor, which only *follows* the main motor, always pushing in the direction of rotation, but without power enough to materially accelerate the speed of the main motor. Are there any objections to this worm gear?

11 Hoisting: The circuit is closed simultaneously on both motors to hoist, the speed of motor *3* will vary about 10 per cent with the varying load, motor *12* is controlled to run at slightly relatively higher speed than the highest speed of motor *3*, but being compound wound for 20 per cent speed variation with the load, it can be retarded 10 per cent or 15 per cent by motor *3* without excess of current. About 30 per cent of current taken by motor *12* relieves motor *3* of that amount of load.

12 Lowering: Motor *12* acts the same as in hoisting, trying to drive motor *3* as a generator slightly faster than the load drives it, returning to the line through motor *3*, 30 per cent of the current that it takes from the line.

13 Worm gear action: In whichever direction worm *10* starts to drive gear *9*, it maintains its pressure on the teeth of gear *9* in that same direction from start to stop. But when motor *3* has come to nearly a stop, motor *12*, either by dynamic action, small friction brake or open circuit, comes to a full stop, and worm *10* positively locks gear *9*, sheave *4* and car *6* against further motion.

14 Thus in the normal operation of hoisting or lowering, motor *12* can do nothing else but drive motor *3*.

15 But in the event of accident to either motor, failure of current, etc., worm *10* will either hold gear *9* stationary, stop it or keep it from exceeding its normal speed.

16 Result of short-circuiting motor *12:*

- *a* Its fuse or circuit breaker opens to the line.
- *b* Its armature continues to revolve by its momentum.
- *c* If its shunt field is open, it starts to generate current through its series field, but *reversing* the direction of the current, demagnetizing and building up a new field, and a weak field at that, as it is only about one-fourth compounded. If its shunt field is not opened, then the shunt and series fields oppose each other, and no dynamic action can occur to stop motor *12*. Where does the danger lie in a short circuit?

17 The increased efficiency, improved motion, simplified and more reliable control predicted in my original paper, are not important to this elevator at present. It is simply a question of this one element of safety, namely, all other standard passenger elevators have had a *positive* resistance to the action of gravity, while this elevator *has no positive resistance* to the action of gravity. And by *positive* resistance I mean a resistance to acceleration by gravity that can not be overcome by anything short of the actual breakage of parts; and the usual least factor of safety of 8 makes breakage of any part a remote possibility, as the record of safety in the past is the best evidence.

18 It is a serious matter for any elevator manufacturer to depart from this standard of safety, inviting people to ride on elevators in which the disturbance of an electric circuit leaves nothing but the inertia of the moving mass to retard the acceleration, and automatic devices which have no *positive* action to check excess of speed. No

economy of operation or any other consideration whatever can justify this risk.

19 The means that I have described provide this elevator with a *positive* resistance to the action of gravity, at no material loss in efficiency, with no change whatever in the functions and control of this elevator as it is now made, and at no material increase in cost, weight or size. It can be attached to existing elevators of this type.

20 The responsibility for the safety of passenger elevators rests as much on the engineers representing the owners of the buildings where they are installed, as it does upon the manufacturer. Every one of these engineers will read this paper. I ask them personally—*You know the risk and the remedy, what are you going to do about it?*

No. 1162

PROCEEDINGS OF THE NEW YORK MEETING

The Fifty-sixth meeting was the first annual meeting of the Society held in the Engineering Societies Building. The attendance was without a parallel, there being more than thirteen hundred members and guests present. The foyer of the building met adequately the requirements for registration and proved a convenient meeting place for renewing old acquaintances and making new. The facilities of the coat room were fully tested and were found equal to the demands of quick and efficient service. The corridors around the auditorium provided opportunity for conversation between members without interrupting the professional sessions.

The numerous auditoriums, adapted for audiences of different sizes, provided means for simultaneous sessions. A meeting on gas power was held simultaneously with a symposium on foundry practice, at both of which stereopticons were used, which are a part of the regular equipment. As an outcome of the interest in the gas power session a section of gas power engineering was formed.

TUESDAY EVENING

The opening session was held on Tuesday evening in accordance with the established custom, at which was given the address of the President upon "The Mechanical Engineer, and the Function of the Engineering Society."

Probably no one is better able to define the duties of the mechanical engineer; to lay down the broad principles of the usefulness of the profession to the advance of civilization, and to point out its ideals, than President Hutton. His duties as a teacher of young engineers, and as Secretary for so many years of the national organization, and finally as its President, have brought him into such intimate touch with the academic and practical phases of the profession that he is eminently qualified to speak with authority.

The report of the Tellers of election was read, which declared the following officers elected:

President

M. L. Holman

Vice-Presidents

L. P. Breckenridge — Fred J. Miller

Arthur West

Managers

Wm. L. Abbott — Alex C. Humphreys

Treasurer

Wm. H. Wiley

After the address by the retiring President, the new President, M. L. Holman, of St. Louis, Mo., who served the Society as Vice-President in 1894–1896, and 1903–1905, was escorted to the chair by the much esteemed Honorary Members of the Society, Prof. John E. Sweet and Mr. John Fritz.

After the formal inauguration of the new President, the meeting was dismissed.

The informal reception that followed was one of the pleasant social functions of the meeting and was greatly enhanced by the presence of several of the Honorary Members.

THE WEDNESDAY MORNING SESSION

The Wednesday morning session was devoted to the subject of gas power and to the reports of standing and special committees, and the general transaction of business. The reports of the committees, Finance, Land and Building, Meetings, Publication, Membership, Standardization and Library were presented. They are published in this volume in the Annual Report of the Council and the Committees. The tellers of election of members made their report at this time, and announced the election of 373 members, whose names are published in the complete record of the business transacted at this meeting. See Appendix.

WEDNESDAY MORNING SESSION

"THE RATIONAL UTILIZATION OF LOW GRADE FUELS IN GAS PRODUCERS"....................................F. E. Junge

Discussed by,

Prof. C. E. Lucke, Prof. R. H. Fernald, E. J. Kunze, Romyn Hitchcock, Prof. Wm. Kent, C. G. Atwater, W. B. Chapman, L. R. Pomeroy, W. H. Blauvelt, R. K. Klein, R. E. Mathot, Dr. J. A. Holmes, H. H. Suplee, J. R. Bibbins.

"DUTY TEST ON GAS POWER PLANT"................J. R. Bibbins

Discussed by,

W. H. Blauvelt, Prof. William Kent, Prof. C. E. Lucke, Prof. S. A. Reeve, Prof. L. P. Breckenridge, R. E. Mathot, C. L. Straub, Prof. W. D. Ennis, W. H. Morse.

"CONTROL OF INTERNAL COMBUSTION IN GAS ENGINES..............................Prof. C. E. Lucke

Discussed by,

L. H. Nash, Prof. W. H. Kenerson, E. J. Kunze, E. Rathbun, Dr. S. A. Moss, R. E. Mathot.

"EVOLUTION OF THE INTERNAL COMBUSTION ENGINE"..................................Prof. S. A. Reeve

Discussed by

H. H Suplee.

WEDNESDAY AFTERNOON

The members were the guests of Mr. Charles M. Jacobs, chief engineer of the Hudson Companies, on an inspection trip through the tunnel from Hoboken under the Hudson River to Christopher Street, New York. This is the completed tunnel begun over a generation ago by Haskin. The Meetings Committee had previously prepared an interesting article, published in pamphlet form with illustrations, giving a history of the tunnel.

WEDNESDAY EVENING

A lecture on "Color Photography" by Mr. F. E. Ives, honorary member and past president of the New York Camera Club, entertained the members and guests on Wednesday evening. Mr. Ives was assisted by Mr. A. R. Stieglitz, author and editor of photographic works. The lecture was an account of the progress of the art to date. It was illustrated by stereopticon views.

A booklet on color photography, specially prepared by Mr. H. F. J. Porter, member of the Publication Committee of the Society, was distributed at the meeting. It gave a brief history of the development from the first experiments made by Dr. Seebeck of Jena in 1810 to the recent processes discovered by Messrs. Herbert and F. E. Ives Mr. Powrie and Miss Warner and Mr. MacDonough in America; Joly of Dublin, and Messrs. Lumière of Lyons, France.

THURSDAY MORNING SESSION

"THE FOUNDRY DEPARTMENT AND THE DEPARTMENT OF ENGINEERING DESIGN" .... W. A. Bole

Discussed by,

A. B. Carhart, E. N. Trump. A. D. Williams, H. M. Lane, J. E. Johnson, Jr.

"MOLDING SAND" .... A. E. Outerbridge

Discussed by,

E. H. Mumford, H. M. Lane.

"POWER SERVICE IN THE FOUNDRY" .... A. D. Williams

Discussed by,

Frank Richards, E. H. Mumford, M. Ronceray, J. E. Johnson, Jr, S. D. Sleeth, H. M. Lane.

"A FOUNDRY FOR BENCH WORK" ... W. J. Keep and Emmet Dwyer

Discussed by,

E. H. Mumford.

"A VOLUMETRIC STUDY OF CAST IRON" .... H. M. Lane

Discussed by,

E. N. Trump, A. E. Outerbridge, J. E. Johnson, Jr., Prof. R. C. Heck.

THURSDAY AFTERNOON SESSION

"SPECIFICATIONS FOR IRON, AND FUEL AND METHOD OF TESTING FOUNDRY OUTPUT" .... R. Moldenke

"FOUNDRY CUPOLA AND IRON MIXTURES"..............W. J. Keep

Discussed by,

G. R. Brandon, E. H. Foster, Prof. W. W. Bird.

"FOUNDRY BLOWER PRACTICE"......................W. B. Snow

Discussed by,

Prof. A L. Williston, Dr Sanford A. Moss, H. DeB. Parsons D. C. Johnson, E. N. Trump, H. M. Lane, T. S. Bailey, J. R. Fortune and H. S. Wells.

"PATTERNS FOR REPETITION WORK"..................E. H. Berry

Discussed by,

Robert Shirley, E. H. Mumford, H. M. Lane.

"SOME LIMITATIONS OF MOLDING MACHINES".......E. H. Mumford

Discussed by,

M. Ronceray, Harris Tabor.

RECEPTION THURSDAY EVENING

The formal reception was held on Thursday evening at nine o'clock in the Engineering Societies Building, where President F. R. Hutton and Mrs. Hutton, Pres.-Elect M. L. Holman and Mrs. Holman, Secretary Calvin W. Rice and Mrs. Rice received the guests. There was dancing on the fourth floor and supper was served during the evening.

FRIDAY MORNING SESSION

"THE SPECIFIC HEAT OF SUPERHEATED STEAM"..Prof. C. C. Thomas

Discussed by,

Prof. C. H. Peabody, J. A. Moyer, A. R. Dodge, Dr. S. A. Moss.

"ENGINE DESIGN ADAPTED FOR THE USE OF SUPERHEATED STEAM"......................Max E. R. Toltz

Discussed by,

H. Emerson, Prof. F. R. Hutton, H. H. Suplee, Prof. C. E. Lucke, R. T. Ode, J. A. Seymour, I. E. Moultrop, Prof. Wm. Kent.

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"POWER TRANSMISSION BY FRICTION DRIVING". Prof. W. F. M. Goss

"CYLINDER PORT VELOCITIES" . . . . J. H. Wallace

"INDUSTRIAL EDUCATION" . . . . W. B. Russell

Discussed by,

H. L. Gantt, C. W. Cross, Geo. W. Rink, L. D. Burlingame, Henry Gardner, Prof. Gaetano Lanza, Prof. A. L. Williston, H. F. J. Porter, F. A. Waldron, W. J. Kaup, O. E. Perrigo, A. L. Rice.

INVITATIONS

The members of the Society were the recipients of further invitations to visit places of engineering interest in the vicinity of New York.

J. H. McGraw, Esq., president of the McGraw Publishing Company, invited the members to visit his six-story building constructed entirely of reinforced concrete, and of unique construction. This building is not only a complete office building, but in addition contains the Times Square sub-station of the New York Post Office, and also the complete printing establishment of the McGraw Publishing Company.

Mr. F. H. Stillman, Member of the Society, of the firm of The Watson-Stillman Company, exhibited at his works at Aldene, New Jersey, a 300 horse power gas producer and engine. Several parties availed themselves of the invitation to visit the plant.

Mr. D. L. Hough, Member of the Society and president of The United Engineering and Contracting Company, gave personal supervision to parties visiting the Pennsylvania Company's cross-town tunnel work.

SOCIETIES OFFICIALLY REPRESENTED AT THE ANNUAL MEETING

La Société des Ingenieurs Civils de France was officially represented by M. Delafond.

The National Fire Protection Association was represented by their Editor, Mr. Henry A. Fiske.

SECTION ON GAS POWER ENGINEERING

At the conclusion of the annual meeting, the following members petitioned the Society for permission under the Constitution to form a section on gas power engineering.

Albert A. Cary, New York.
Jas. V. V. Colwell, New York.
Geo. D. Conlee, Ithaca, N. Y.
R. H. Fernald, Cleveland, O.
Alex R. Goldie, Ontario, Can.
John A. Laird, St. Louis, Mo.
Fred R. Low, New York.
Charles E. Lucke, New York.
D. T. MacLeod, Camden, New Jersey.
R. E. Mathot, Brussels, Belgium.
Edward Robinson, Burlington, Vt.
Geo. I. Rockwood, Worcester, Mass.
C. W. Scribner, New York.
Arthur K. Spotton, Galt, Canada.
F. H. Stillman, New York.
A. F. Stillman, New York.
H. H. Suplee, New York.

Others, guests of the Society, signing the petition:

J. C. Barnaby, New York.
W. B. Chapman, Hew York.
W. R. Huttinger, Beverly, N. J.
F. E. Junge, Berlin, Germany.
J. S. Lane, Brooklyn, N. Y.
L. B. Lent, New York.
J. W. Lowell, New York.
G. F. F. Osborne, Toronto, Canada.
Frank C. Tryon, New York.
A. J. Verkouteren, Flushing, L. I.
C. T. Wilkinson, Schenectady, N. Y.

Mr. H. H. Suplee was chosen Secretary of the informal meeting and presented the matter to the Council. The Council cordially received the petition and immediately appointed a Committee on Affiliated Societies, consisting of:

F. R. Hutton, *Chairman*,
Alex C. Humphreys
R. H. Fernald
H. H. Suplee
F. W. Taylor

to confer with a committee of the members and arrange the details in conformity with the rules of the Constitution already prepared for the formation of sections.

The President's address, dealing with the Society's broader usefulness involved in extending its interest in this manner was also referred to this committee for consideration and report.

Relics of Engineering Interest

ERICSSON MODELS

Objects of interest displayed in the Reception and Board rooms of the Society during the convention were the Ericsson models, recently acquired from Mr. G. N. Robinson, executor of the Ericsson estate. These have, until the present time, been on view at the Metropolitan Museum of Art, but are now to be permanently exhibited in the Engineering Societies Building.

GEAR CUTTER

A gear cutter made and used at the works of Russell, Birdsall and Ward, Port Chester, New York, in 1848, has been presented to the

Society by Mr. A. D. Finley, Associate Member. The cutter was formed on a lathe with the old style hand tool and the teeth were cut with a file. The milling machine on which it was used was also made by the firm. It was invented by Mr. W. E. Ward, and run under his supervision. Most of the work on the machine was chipped with a chisel and finished with a file, as they did not have any planer or shaper for this class of work.

Both bevel and miter gears were cut on it, with fairly good results. The worm wheel on the work spindle was cut by revolving a tap in a lathe and holding the disk against it.

WATT AND FULTON RELICS IN THE POSSESSION OF THE SOCIETY

Through the kindness of Mr. H. H. Suplee, editor of Cassier's Magazine and Member of the Society, we are able to show reproductions of very interesting relics which have recently been placed in the custody of the Society.

Fig. 1 shows a copper plate impression of the Certificate of Membership in the Insurance Society of the Soho Manufactory of Boulton and Watt at Birmingham. This certificate, together with two other impressions, was found in Heathfield Hall, in the room in which James Watt did his private experimental work. It was found by Mr. George Tangye in 1903, sealed with the seal of James Watt. Mr. Tangye sent the certificate to Prof. John E. Sweet, who now transfers it to this Society as being a logical depository for such relics.

Fig. 2 shows the interior of James Watt's work room in Heathfield Hall in which the package was found. The room was allowed by Mr. Tangye, the subsequent owner, to remain exactly as Watt left it.

Attention is directed to portions here shown of the carving and duplicating machine upon which Watt was engaged at the time of his death, in 1819.

Fig. 3 shows an interesting document relating to the work of Robert Fulton which Mr. Suplee himself presented to the Society.

At the time Napoleon was preparing his projected invasion of England, from 1802 to 1805, Fulton, then a resident of France, offered to him a plan for the steamboat as a means of conveying his troops across the channel, during calm weather, when the British sailing vessels would be powerless. For some time the original record of this offer of Fulton's could not be found, but it is now known to be in the archives of the *Conservatoire des Arts et Métiers* in Paris, and, through the efforts of a friend, M. Jacques Boyer, Mr. Suplee stated that he had succeeded in obtaining a photograph of it. This photograph includes a four-page letter in the handwriting of Fulton, describ-

FIG. 1 CERTIFICATE OF MEMBERSHIP IN THE INSURANCE SOCIETY OF SOHO MANUFACTORY OF BOULTON & WATT, RECENTLY DISCOVERED AMONG THE PAPERS LEFT BY WATT, AND PRESENTED TO THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS BY PROF. JOHN E. SWEET. ONE-HALF SIZE OF THE ORIGINAL

ing fully his plans for steam navigation, together with a complete drawing of the steamboat, representing the machinery practically as it was subsequently employed on the Clermont. This letter is addressed to the Commission to whom Fulton was referred by Napoleon, consisting of MM. Molard, Bandell, and Montgolfier, but their adverse report prevented the plan from being put into execution, otherwise it is possible that the fate of Europe might have been changed. It is interesting to note that Montgolfier, the inventor of the

FIG. 2 WATT'S WORK ROOM AT HEATHFIELD HALL

balloon, was a member of the commission that rejected Fulton's plan.

These documents are dated 4 Pluviose, year XI, in the French Republican Calendar, corresponding to January 25, 1803, thus antedating by about three and a half years the first trip of the Clermont on the Hudson.

Following is a translation made by Mr. Suplee of the letter of Fulton to the French Commission:

Letter of Fulton to the French Commission

[Translation]

PARIS 4 Pluviose, Year XI (25 January, 1803).

Robert Fulton to Citizens Molar, Bandell and Montgolfier.

FRIENDS OF THE ARTS—I send you herewith sketch designs of a machine which I am about to construct with which I propose soon to make experiments upon the towing of boats upon rivers by the aid of fire engines. My original object in attempting this was to put it in practice upon the great rivers of America where there are no roads suitable for hauling nor indeed are any hardly practicable, and where, in consequence, the cost of navigation by the aid of steam would be put in comparison with the labour of men and not with that of horses as in France.

You can see that such a discovery, if successful, would be infinitely more important in America than in France where there exists everywhere roads suitable for hauling, and companies established for the transport of merchandise at such moderate charges that I doubt very much if a steam boat, however perfect it might be, could be able to gain anything over horses for merchandise. But for passengers it is possible to gain something because of the speed.

In these plans you will find nothing new, since this is not the case with paddle wheels, an appliance which has often been tried and always abandoned because it was believed that it had a disadvantageous action in the water. But, after the experiments which I have made already I am convinced that the fault is not in the wheel, but in the ignorance concerning its proportions, its speed, the power required, and probably in the mechanical combination.

FIG. 4 SKETCH IN FULTON'S LETTER

I have proved by very accurate experiment that paddle wheels are much to be preferred to bands of paddles, and in consequence, although the wheels are not a new application, yet nevertheless I have combined them in such a manner that a large portion of the power of the engine acts to propel the boat in the same way as if they rolled upon the ground; the combination is infinitely better than anything which has as yet been done up to the present time, and it is in fact a new discovery.

For the transport of merchandise I propose to use a boat with an engine arranged to draw one or several loaded barges, each one so close to the preceding one that the water cannot flow between to make resistance. I have already done this in my patent for small channels, and this is indispensable for boats moved by fire engines.

Suppose the boat *A*, with the engine, presents to the water a face of 20 feet, but inclined at an angle of 50 degrees, it will be necessary to have a machine of 420 pounds power making 3 feet per second to move one league per hour in still water. If the boats *B* and *C* have their faces parallel to that of *A* they will each also require a force of 420 pounds, that is to say 1200 pounds for the three, while if they are connected in the manner in which I have indicated, the force of 420

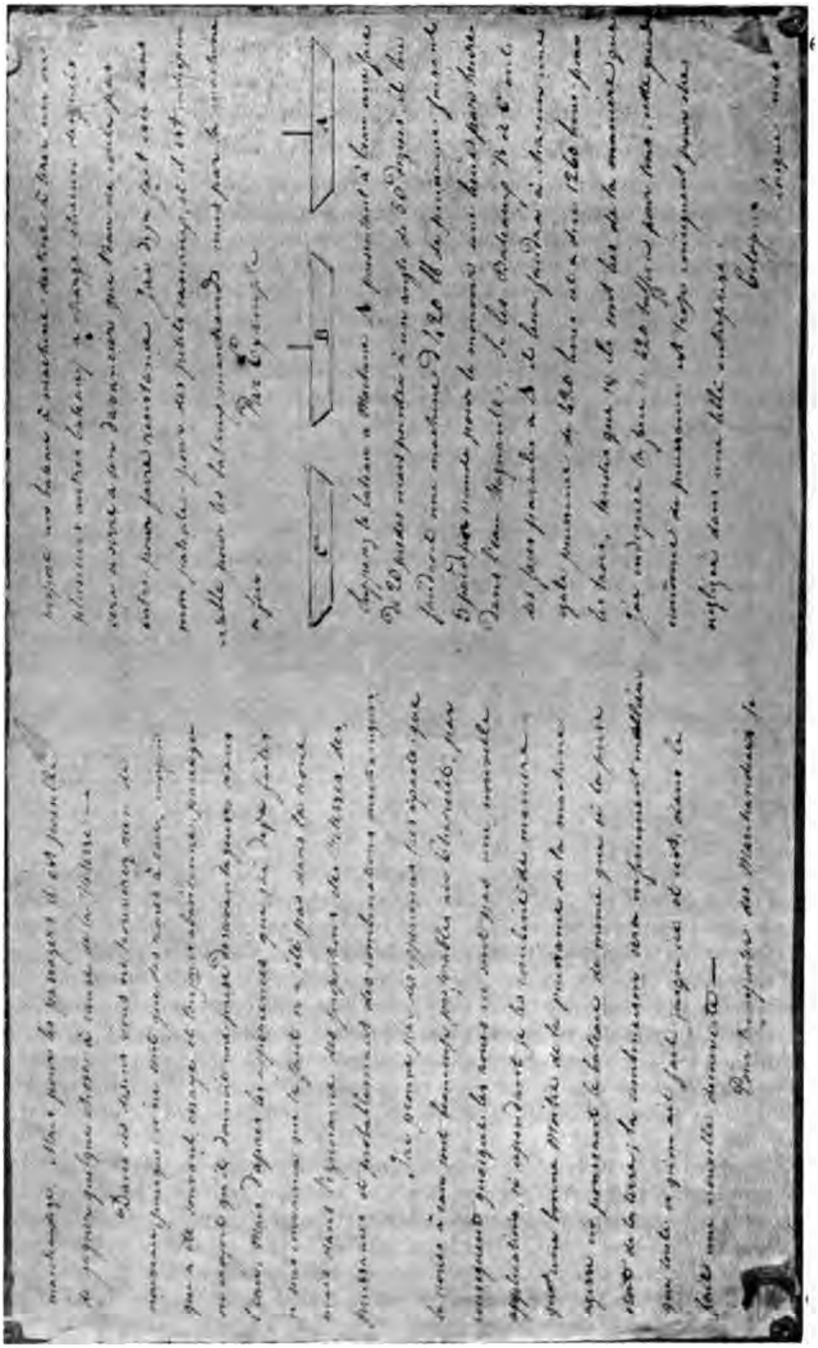

Fig. 3 Fac-simile of the Letter of Fulton to the Commission Appointed by Napoleon in 1803. From the Original in the Conservatoire des Arts et Métiers, Paris, France

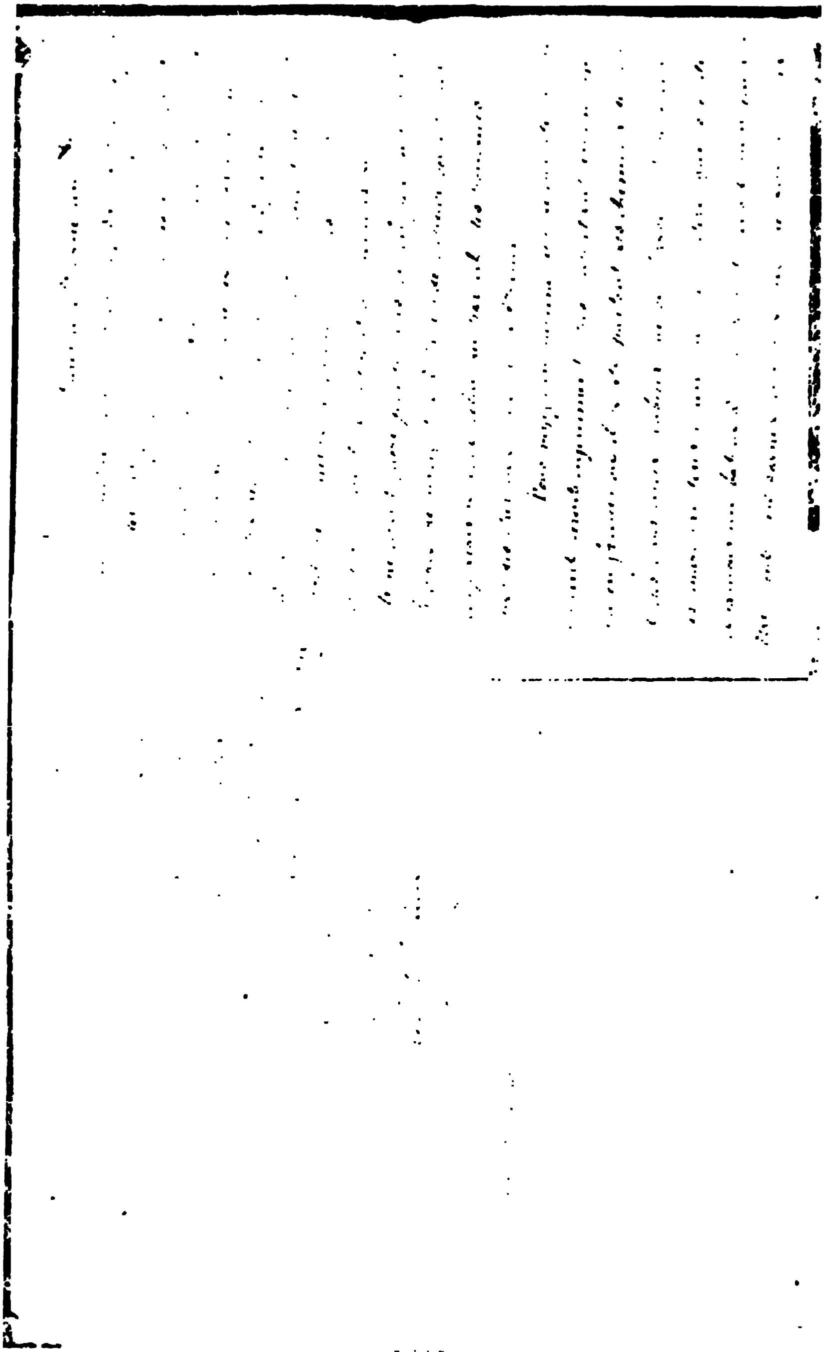

FIG. 3 FAC-SIMILE OF THE LETTER OF FULTON TO THE COMMISSION APPOINTED BY NAPOLEON IN 1803. FOR TRANSLATION, SEE PAGE 119

pounds will suffice for all, and this great economy of power is too important to be neglected in such an undertaking.

Citizens:

When my experiments are ready I shall have the pleasure to invite you to see them, and if they are successful I reserve the privilege of presenting my labours to the republic or of taking for them such advantages as the law may authorize. At the present time I place these notes in your hands in order that if any similar project comes before you before my experiments are completed, they shall not have the preference over mine.

With respectful salutations,

ROBERT FULTON

No. 50 Rue Vaugirard

The relics described above are on display in the Society rooms, and members are cordially invited to request to see them when visiting the headquarters.

APPENDIX

CONSOLIDATION OF THE MECHANICAL ENGINEERS LIBRARY ASSOCIATION AND THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

The consolidation of the Mechanical Engineers Library Association and The American Society of Mechanical Engineers was effected on October 21, 1907, the reason for the separate existence of the two corporations having disappeared with the acceptance by The American Society of Mechanical Engineers of the building of the United Engineering Societies at 29 West 39th Street, New York, and the removal there of the Library and the Society's headquarters.

For the purpose of maintaining a library of engineering, the Mechanical Engineers Library Association was incorporated in 1890 under the laws of the State of New York. Upon its corporation the property at 12 West 31st Street was purchased in its name for the sum of $60 000; the Library Association issuing bonds for $27 000, all the cash paid toward the purchase price. Subsequently the Society took up the bonds.

The library was always owned by the Society. After the removal of the Society headquarters and its library to the building of the Engineering Societies, the Mechanical Engineers Library Association applied to the Supreme Court for leave to sell the property at 12 West

31st Street, which permission was granted on March 20, 1907, and the property sold for the sum of $120 000. Of this $33 000 was used to pay the mortgage, and the balance, less costs of the sale, was retained.

After selling the real estate, there being no reason for the separate existence of the two corporations, it was desired by both to consolidate.

On September 16, 1907, the Trustees of the Association and the Council of the Society executed an agreement for the consolidation in accordance with Section 7 of the Membership Corporation Law of the State of New York, the consolidated corporation to be known by the name of The American Society of Mechanical Engineers.

The Petition and Agreement for Consolidation were submitted to a meeting of the members of the Society, specially called for that purpose, on October 8, 1907, and were approved by a vote of more than three-fourths of the members present.

The Petition and Agreement for Consolidation were likewise submitted to a meeting of the Fellows of the Association, specially called for that purpose, on October 15, 1907, and were approved by a vote of more than three-fourths of the members present.

The Petition to the Court stated that it is the intention of the two Societies to maintain a library at the United Engineering Society Building at 29 West 39th Street, New York, similar to that heretofore maintained at 12 West 31st Street; that the library is now, and will be, maintained as a free public library; that access to it will not be limited to members of the two corporations, but in a public-spirited way will be held open freely to the public and to all desiring to consult the books contained therein.

The Order for Consolidation was granted on October 21, 1907, by Justice Blanchard of the Supreme Court of the State of New York.

The petitions were published in full in the Mid-November, 1907, Proceedings, Vol. 29, No. 5, and the Charter appears annually in the Year Book.

IMPORTANT CHANGE IN THE DATE OF TRANSACTIONS

Upon the recommendation of the Publication Committee and the approval of the Council the Transactions will in future cover the calendar year instead of the fiscal year.

This change will aid the memory in locating papers according to the year in which a paper was presented and also secure in one volume all of the work of one administration.

In accordance with the provision of C59 the Society is hereby advised of the following addition to the By-Laws made by the Council on May 30, regular notice of such two additions having been given at the meeting of the Council on April 16.

B 44 That standards for the conduct of the business affairs of the Society of its professional or business meetings, and of its committees and their activities may be established, amended, and annulled by a two-thirds vote of the members of the Council present at a meeting, provided that a written notice of the proposed addition or change may have been given at a previous meeting of the Council, and provided further that the Secretary shall have sent to each member of the Executive Committee, acting as a Committee on Standards, a draft of the proposed addition or change at least two weeks prior to the meeting at which they are to be voted on.

B 45 That directions for the conduct of the business affairs of the Society may be established by the Secretary and the work covered shall be carried out as provided by these directions. These directions may be added to, amended, or annulled by the Secretary but it shall be his duty to send to each member of the Executive Committee, acting as a Committee on Standards, a draft of the change before it is put into effect.

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS TO COÖPERATE WITH THE SOCIETY FOR THE PROMOTION OF ENGINEERING EDUCATION

The President of the Society appointed Dr. Alex C. Humphreys and Dr. Frederick W. Taylor as members of a Joint Committee to coöperate with the Society for the Promotion of Engineering Education, together with representatives of other National Engineering Societies, in the examination of all branches of engineering education, including engineering research, graduate professional cour es, undergraduate engineering instruction and the proper relations of engineering schools to the secondary industrial schools or foremen's schools, and to formulate a report or reports upon the appropriate scope of engineering education and the degree of coöperation and unity that may be advantageously arranged between the various engineering schools.

The Council of the Society for the Promotion of Engineering Education will confer with the membership of the Joint Committee, and a report of the progress of the work of the Joint Committee will be made to that Society within a year and a final report within two years.

ELECTIONS TO MEMBERSHIP

The following were declared elected to membership in the Society upon the ballot of June 30, July 25, and November 28, 1907:

Ballot June 30, 1907

MEMBERS

Anderson, Robert, Ivorydale, Ohio.
Banta, Earle, Culebra, Canal Zone.
Bird, Paul P., Chicago, Ill.
Bixby, A. S., Indianapolis, Ind.
Blake, E. M., Tucson, Arizona.
Boyden, George A., Baltimore, Md.
Boyd, William C., Pittsburg, Pa.
Bradley, Carl D., Elizabethport, N. J.
Brewer, Henry, New Haven, Conn.
Briggs, William C., Elizabethport, N. J.
Brooks, Henry K., New York.
Burgoon, C. E., New York.
Caldwell, John A., New York.
Carpenter, James M., Pawtucket, R. I.
Chamberlain, G. E., Chicago, Ill.
Christianson, A., Butler, Pa.
Conrath, George B., Erie, Pa.
Dodge, Austin, R., Schenectady, N. Y.
Fannon, William A., Appleton, Wis.
Faull, Richard, Birmingham, Ala.
Ford, Bruce, Philadelphia, Pa.
Frederick, Floyd Willis, Stroudsburg, Pa.
Garratt, Ernest A., London, England.
Gray, William Emery, Williamsport, Pa.
Greul, W. Herman, New York.
Hadfield, R. A., London, England.
Hamilton, R. B., St. Catherines, Canada.
Heermann F. M., Boston, Mass.
Hendry, W. F., New York.
Huyette, William S., Chicago, Ill.
Johnston, John Parry, Chicago, Ill.
Lacount, H. O., Boston, Mass.
Lake, Simon, Bridgeport, Conn.
Lane, H. C., Sparrows Point, Md.
Lincoln, P. M., Pittsburg, Pa.
McClure, O. D., Ishpeming, Mich.
Mackenzie, W. P., Harrisburg, Pa.
MacLauchlan, James H., New York.
Marks, Harry J., New York.
Moyer, J. A., West Lynn, Mass.
Neiler, Samuel G., Chicago, Ill.
Nesbit, Edwin, Cleveland, Ohio.
Noble, Alfred, New York.
Osteman, C. G., South Boston, Mass.
Payne, Sheldon F., Naugatuck, Conn.
Pearson, Walter A., Niagara Falls, Ont.
Perry, Ernest B., Bay City, Mich.
Pillmore, Frederick, Syracuse, N. Y.
Primrose, John, New York.
Pulsifer, H. M., Chicago, Ill.
Rink, George W. Jersey City, N. J.
Spoerri, H., Zurich, Switzerland.
Spurling, O. C., Chicago, Ill.
Stone, Charles W., Schenectady, N. Y.
Stucki, A., Pittsburg, Pa.
Summey, D. L., Waterbury, Conn.
Taylor, A., Pittsburg, Pa.
Thomson, T. Kennard, New York.
Todd, Robert I., Indianapolis, Ind.
Traylor, Bruce W., New York.
Von Phul, William., New Orleans, La.
Wadleigh, George R., Bemis, Tenn.
Wilder, Clifton W., New York.
Wilkinson, John, Syracuse, N. Y.
Williams, Llewellyn, Boston, Mass.
Wright, R. V., East Orange, N. J.

PROMOTED TO MEMBER

Comly, G. Norwood, Syracuse. N. Y.
Ennis, William D., Schenectady, N. Y.
Haight, H. V., Sherbrooke, Que.
Kutter, H. L., Hamilton, Ohio.
Patitz, Gerhardt J., Chicago, Ill
Stovel, R. W., New York.
Wood, B. F., Altoona, Pa.

ASSOCIATES

Artaud, Theodore P., New York.
Bishop, Frank, South Bend, Ind.
Cox, Claude E., Indianapolis, Ind.
Craig, Robert, Minneapolis, Minn.
Davidson, Archer, Atlanta, Georgia.
Deacon, Ralph Woolman, Chrome, N. J.
Dunkle, H. Edward, Syracuse, N. Y.
Fitch, Alfred L., Chicago, Ill.
Lillibridge, Ray D., New York.
Miller, F. L., Philadelphia, Pa.
Muther, Ellis F., New York.
Myers, David Moffat, New York.
Rose, J. H., Bradford, Pa.
Schroeder, F. A., Boston, Mass.
Shipley, Grant B., Milwaukee, Wis
Sirich, J. Henry, Jr., New York.
Speer, C. H., West New Brighton, N. Y.
Teague, Walter Owen, Lafayette, Ind.
Veal, C. B., Lafayette, Ind.

PROMOTED TO ASSOCIATE

Gibson, George H., New York.
Nicklin, Ernest W., Detroit, Mich.
Van Zandt., Paul C., Chicago, Ill.

JUNIORS

Anderson, Howard L., Pittsburg, Pa.
Carden, William H., Chicago, Ill.
Cushman, Frank, Jr., Kansas City, Mo.
Davis, George H., Pawtucket, R. I.
De Haven, Irvin Clifton, Indianapolis, Ind.
Dorner, Frederick H., Milwaukee, Wis.
Faile, Edward Hall, New York.
Frohwein, Richard W., New York.
Fuller, Floid M., Boston, Mass.
Garrett, J. A., Los Angeles, Cal.
Hackett, George E., Roselle, N. J.
Hutchings, C. F., New York.
Hvid, R., Minneapolis, Minn.
Jacobus, Robert F., New York.
Jenkins, A. Lewis, Cincinnati, Ohio.
Matty, Leo. J., New York.
McKee, N. T., Collinwood, Ohio.
Merz, Robert George, Newark, N. J.
Mueller, Otto N., Indianapolis, Ind.
Mueller, Victor H., Newark, N. J.
Polland, Willard Lacy, Waukesha, Wis.
Pryor, R. W., Jr., New York.
Reese, Dale F., Newark, N. J.
Rigdon, Carl, Columbus, Ohio.
Scales, H. J., Massena, N. Y.
Schwartz, H. A., Indianapolis, Ind.
Spencer, J. Beaumont, New York.
Taddiken, J. F., Jr., New Orleans, La.
Thomas, G. C., Bridgeport, Conn.
Zimmermann, John E., Philadelphia, Pa.

The following were declared elected to membership in the Society upon the ballot of July 25, 1907.

BALLOT JULY 25, 1907.

MEMBERS

Atkins, David F., San Francisco, Cal.
Ballard, F. W., Cleveland, Ohio.
Bayle, E. J., Denver, Col.
Bennett, Joseph A., Hartford, Conn.
Bixler, H. Z., Hamilton, O.
Blakeley, G. H., South Bethlehem, Pa.
Brady, J. H., Kansas City, Mo.
Buker, Henry, Providence, R. I.
Burr William H., New York.
Clarke, F. G., Long Island City, N. Y.
Coffin, H. E., Detroit, Mich.
Daggett, H. C., Boston, Mass.

Darby, John, New York.
Douglas, E. R., Poughkeepsie, N. Y.
Doying, W. A. E., New York.
Ekstrand, L. M., Waukegan, Ill.
Ferris, Walter, Milwaukee, Wis.
Flannery, John M., Syracuse, N. Y.
Goss, Harry T., New York.
Harper, John, Chicago, Ill.
Harris, G. A., New York.
Hearne, Robert J., New York.
Hill, E. Rowland, New York.
Holman, R. Claude, Hamilton, Ohio.
Johnson, F. Amos, South Orange, N. J.
Jones, J. E., New York.
Klepinger, J. H., Great Falls, Mont.
Knowles, Morris, Pittsburg, Pa.
Kunze, E. J. Newark, N. J.
Larson, Charles J., New York.
Lockwood, B. D., Indianapolis, Ind.
McKee, Arthur G., Cleveland, Ohio.
McKinney, E. B., New Orleans, La.
McMahon, F. J., Wilkesbarre, Pa.
Metcalf, F. M., Battle Creek, Mich.
Mills, Charles, Newton Upper Falls, Mass.
Norton, Fred E, Youngstown, O.
Reed, Warren B., New Orleans, La.
Reid, Robert C., Englewood, N. J.
Rouvel, George W., La Salle, Ill.
Royle, Vernon, Paterson, N. J.
Scott, Henry F., South Framingham, Mass.
Simpson, Colin C., New York.
Southworth, Martin O., Chicago, Ill.
Sutton, Frank, New York.
Sweet, Charles E., E. Pittsburg, Pa.
Talcott, R. Barnard, New York.
Wainright, L. M., Indianapolis, Ind.
Walker, S. G., Providence, R. I.
Wall, W. G., Indianapolis, Ind.
Weichert, A. E., New York.
Wickersham, N. R., Painted Post, N.Y
Wood, Henry Shotwell, New York.
Woodward, Harry W., Cleveland, Ohio.
Woolson, Harry T., New York.

PROMOTED TO MEMBER

Boyer, Charles W., Somerville, Mass.
Boyer, E. S., New York.
Catlin, A. D., Chattanooga, Tenn.
Herbert, Frederick D., Hewitt, N. J.
Hitchcock, Frederick M., New York.
Hollingsworth, Samuel, Plainfield, N. J.
Ilsley, John Parker, New York
Keely, R. R., Edmonton, Canada.
Macleod, D. T., Merchantsville, N. J.
Miller, J. S., Milwaukee, Wis.
Rutherford, Gordon Scott, Detroit, Mich.
Schaeffler, Joseph C., Boston, Mass.
Thompson, Albert William, Manchester, N. H.
Wehner, Louis, Cincinnati, O.
Weinberg, S. G., St. Petersburg, Russia.

ASSOCIATES

Anderson, Emanuel, Mexico, D. F. Mexico.
Anderson, Harry W., Atlanta, Ga.]
Bavier, C. S., New York.
Birdsey, C. R., Chicago, Ill.
Bruyere, Paul T., New York.
Buerger, Charles B., Philadelphia, Pa.
Christie, A. G., New York.
Clarke, C. W. E., New York.
Dart, William C., Providence, R. I.
Fogg, Oscar H., New York.
Hagar, Arthur P., Jersey City, N. J.
Hanna, H. H., Jr., Indianapolis, Ind.
Hart, Rogers B., Scranton, Pa.
Hill, Charles Hubbard, Schenectady, N. Y.
Hiller, Joseph, L., Philadelphia, Pa.
Larner, Chester W., Cleveland, O.
McMullen, V. E., Beloit, Wis.
Macbeth, Colin, Indianapolis, Ind.
Perkins, G. Hawthorne, Lowell, Mass.
Place, Clyde R., New York.
Seawell, Bert W., Cincinnati, Ohio.
Sellew, Ernest Burchard, Pawtucket, R. I.
Slade, Foster, Cornell, New York.
Weston, F. W., New York.
Wilson, J. W., New York.

PROMOTED TO ASSOCIATE

Eberhardt, Elmer G., Newark, N. J.
Lockett, Kenneth, Chicago, Ill.
Schaefer, Edward F., New York.
Whitney, Marshall L., Tucson, Arizona.

JUNIORS

Aylsworth, J. W., New York.
Bates, A. H., Muskegon, Mich.
Core, W. Wallace, Newark, N. J.
Cork, R. L., Fort Wayne, Ind.
Cressler, Kerr Murray, Fort Wayne, Ind.
Davis, E. H., Brooklyn, N. Y.
Dillard, James B., Sandy Hook Proving Ground, N. J.
Dodwell, J. G., New York.
Flagg, S. B., Alton, Ill.
Hale, A. A. Chicago, Ill.
Hamerstadt, W. D., Indianapolis, Ind.
Howard, Charles A., New York.
Lee, Robert E., New York.
Mellowes, Alfred W., New York.
Percy, Earl Newman, New York.
Philbrick, H. S., Colombia, Mo.
Pitkin, Arthur F., Schenectady, N.Y.
Posey, James, Baltimore, Md.
Posselt, Ejnar, St. Louis, Mo.
Steele, Ben W., Dothan, Ala.
Stevenson, Louis T., Pittsfield, Mass.
Uihlein, W. B., Milwaukee, Wis.
Wheeler, Earl, Washington, D. C.
Woods, Samuel H., New York.
Wright, C. Shelor, Calhoun, Georgia.
Yates, R. L., Dayton, O.

Ballot November 28, 1907

MEMBERS

Basinger, J. G., New York.
Beckwith, Arthur K., Dowagiac, Mich.
Bentley, Harry, Whitehaven, Eng.
Bodwell, Howard, L., Monessen, Pa.
Boyd, James C., New York.
Briggs, Arthur James, Syracuse, N. Y.
Britton, John A., San Francisco, Cal.
Carpenter, C. U., New York.
Coffin, Frank M., New York.
Coleman, F. A., Cleveland, Ohio.
Cranston, Robert E., Sacramento, Cal.
Ellis, Frank I., Pittsburg, Pa.
Elvin, A. G., Franklin, Pa.
Evans, William Penn, Portland, Ore.
Franz, W. G., Cincinnati, Ohio.
Garfield, A. S., Paris, France.
Goldingham, Arthur Hugh, New York.
Henderson, R. H., Bloomfield, N. J.
Herr, H. T., Denver, Col.
Hoerr, Alex. L., McKeesport, Pa.
Hoxie, Frederick Jerome, Phenix, R. I.
Ingham, Howard M., Englewood, N.J.
Inslee, H. C., Newark, N. J.
LeBlond, John A., Cincinnati, Ohio.
Lee, F. V. T., San Francisco, Cal.
Lee, William F., West New Brighton, N. Y.
Lee, W. S., Charlotte, N. C.
McGiffert, J. R., Duluth, Minn.
Mallory, Charles K., Syracuse, N. Y.
Marx, C. W., Indianapolis, Ind.
Merritt, Joseph, Hartford, Conn.
Miles, Henry D., Buffalo, N. Y.
Millholland, W. K., Indianapolis, Ind.
Moody, William Otis, Chicago, Ill.
Naphtaly, Sam L., San Francisco, Cal.
Rankin, W. A., Painesdale, Mich.
Reeder, C. L., Baltimore, Md.
Richardson, Thomas, South Norwalk, Conn.
Schoolfield, Frank R., Brooklyn, N. Y.
Scott, J. W., Edgewater, N. J.
Smith, Julian C., New York.
Walmsley, W. N., Sao Paulo, Brazil.
Warman, W. A., New York.
Wisner, G. M., Chicago, Ill.
Woodward, Sherman M., Washington. D. C.

PROMOTED TO MEMBER

Bacon, C. J., Chicago, Ill.
Berry, Edgar H., New York.
Caracristi, V. Z., Richmond, Va.
Gamper, Herman, Columbus, Ohio.
Harrington, Harry G., Newark, N. J.
Hayward, Henry S., Jr., Franklin, Pa.
Hill, Ebenezer, Jr., South Norwalk, Conn.
Pond, H. O., New York.
Reeder, N. S., Jr., Montreal, Canada.
Waddell, Charles E., Biltmore, N. C.
Webster, William Reuben, Bridgeport, Conn.
Williams, George W., Chicago, Ill.

ASSOCIATES

Barker, F. P., Buffalo, N. Y.
Bogardus, Henry Ashley, Chicago, Ill.
Castanedo, Walter, New Orleans La.
Chamberlin, William Fosdick, Dayton, Ohio.
Collins, Edward C., Taunton, Mass.
D'Ornellas, T. V., Lima, Peru.
Dunn, K. G., San Francisco, Cal.
Fuchs, Hugo, New York.
Humphrey, Clifford W., Chicago, Ill.
Klock, Frank B., Syracuse, N. Y.
Leland, George Benton, Stamford, Conn.
Lummis, Charles W., Camden, N. J.
Niles, F. H., Chicago, Ill.
Scherr, Frederick, Jr., New York.
Simpson, G. T., St. Paul, Minn.
Smith, S. H., Victoria, Australia.
Stoughton, Edwin R., New York.
Streeter, Robert L., Buffalo, N. Y.
Tate, J. M., Jr., Pittsburg, Pa.
Turner, Charles P., New York.
Wilbur, Ralston T., St. Louis, Mo.
Willard, L. L., Brooklyn, N. Y.

JUNIORS

Abrahams, M. L., Philadelphia, Pa.
Adler, Alphonse A., Brooklyn, N. Y.
Bench, Alfred R., Urbana, Ill.
Braun, C. F., San Francisco, Cal.
Brinton, Willard C., E. Pittsburg, Pa.
Buck, Irwin, New York.
Clarke, Philip Lancaster, Schenectady, N. Y.
Coes, H. V. O., New York.
Cole, George William, New York.
Cranston, Raymond Earl, Providence, R. I.
Dodds, William B., Cincinnati, Ohio.
Dwyer, Emmet, Detroit, Mich.
Eberhardt, Frank E., Newark, N. J.
Fieux, Ernest D., New York.
Fritz., A. L. G., Boston, Mass.
Gillan, Howard A., Hagen, Germany.
Heizmann, Lewis J., Reading, Pa.
Hollmann, F. W., Sparrows Point, Md.
Johnston, J. M. A., Richmond, Va.
Kennedy, H. H., Indianapolis, Ind.
Luehrs, Daniel M., Toledo, Ohio.
Magin, Frank W., Milwaukee, Wis.
Martin, Edward J., Bantam, Conn.
Marx, August, Cincinnati, Ohio.
Mott, Abram Cox, Jr., Philadelphia, Pa.
Newcomb, Robert E., Holyoke, Mass.
Newell, Williams, New York.
Nickerson, Ralph R., Indian Orchard, Mass.
Norris, James U., New York.
O'Keeffe, James Garwood, Newark, N. J.
Rupf, Ernest L., Port Chester, N. Y.
Sar Vant, Wilbur N., New York.
Slocum, Chester Arthur, Long Branch, N. J.
Snyder, Leo H., Jersey City, N. J.
Stillman, Austin Frank, New York.
Stone, Mason A., Jr., Yonkers, N. Y.
String, Joseph S., East Orange, N. J.
Valentine, Louis R., Maurer, N. J.
Watson, H. L., Milwaukee, Wis.
Weissblatt, M. E., New York.
Wilder, Sylvanus Wells, Paterson, N. J.
Wilson, William Lawrence, Chicago, Ill.
Winterrowd, W. H., Elkhart, Ind.

No. 1163

ANNUAL REPORTS OF THE COUNCIL AND THE COMMITTEES, 1907

REPORT OF THE COUNCIL

The Council begs to call the attention of the Society to the detailed reports of the several standing committees as best giving the work and progress of the Society during the past year. In these reports is recorded the removal of the headquarters to the new building of the Engineering Societies, and the removal of the library without loss or damage to a single volume. The property at 12 West 31st Street has been sold at an increase of nearly $60 000 over the purchase price.

In the report of the Land and Building Fund Committee are shown the details of the payments on the present property.

The money received for the sale of the property at 12 West 31st Street has been largely used in the reduction of the mortgage on the property at 29 West 39th Street.

An account of the dedicatory exercises has already appeared in the Proceedings, but will again be published by the Dedication Committee in a separate volume, uniform with the Transactions.

The monthly meetings of the year have been: January, Mr. Frederick P. Fish on "The Ethics of Trade Secrets;" February, Prof. Charles M. Allen, "Gasolene;" Mr. C. E. Sargent, "The Testing of Inflammable Gases;" March, Mr. J. W. Lieb, Jr., "Vesuvius and the Mechanic Arts of Pompeii;" April, Brigadier General William Crozier, "The Ordnance Department as an Engineering Organization;" October, Prof, J. P. Jackson, "College and Apprentice Training;" November, Mr. Charles R. Pratt, "A High Speed Elevator."

The Spring Meeting of the Society in Indianapolis was very successful and well attended and treated of symposiums on superheated steam, automobiles, and various separate discussions on steel tubes, pumping engines, etc.

During the year the Council and Society have elected to Honorary Membership, Mr. Andrew Carnegie, donor of the new building. Honorary Vice-Presidents appointed to represent the Society during the year have been as follows: convention of the National Fire Protection Association, Mr. John R. Freeman and Prof. Ira H. Woolson; centennial celebration of the founding of the University of Tennesee, Mr. Newell Sanders, Prof. Chas. S. Brown and Mr. F. R. Jones; at the unveiling of bronze tablets in the Hall of Fame, New York University, Mr. Jarvis B. Edson, Mr. George R. Henderson, Mr. Benjamin F. Isherwood, Honorary Member of the Society, and Mr. Henry Harrison Suplee; at the fiftieth anniversary of the Michigan Agricultural College, Prof. M. E. Cooley, Alex. Dow, and Mr. F. E. Kirby; for the Hudson-Fulton celebration, the President of the Society in office, and Admiral George W. Melville.

A new Junior badge has been approved by the Council, of the same design and form as the Member's badge but enameled in crimson instead of blue. The reason for the change was that the old form of Junior badge was unlike the recognized emblem of the Society and therefore was not satisfactory. The new badge successfully meets this criticism.

Mrs. George H. Corliss and Miss Corliss presented to the Society the portrait of Mr. George H. Corliss, on the evening of dedication week, before a distinguished audience which had gathered to listen to the address of Brigadier General William Crozier. On Founders Day, a gold medal was presented to Dr. Frederick Remsen Hutton, in token of appreciation of his twenty-four years of service to the Society as its Secretary.

The Secretary reports for record the following deaths during the year: Sir Benjamin Baker, Charles Haynes Haswell, Honorary Members; Charles Harding Loring, Coleman Sellers, Past Presidents; Peter H. Been, Storm Bull, James Blake Cahoon, William H. Derbyshire, George Henry Evans, Edward Francis Gavagan, Abel G. Goldthwait, Eugene Griffin, Albert F. Hall. Charles J. Hillard, Edward Warren Johnson, William Samuel Love, Herbert Clifton Moyer, George Rowland, Thomas Fitch Rowland, William L. Simpson, Charles K. Stearns, Norman C. Stiles, Herman Unzicker, W. H. Wiggin, Thomas Hilton Williams.

Resignations during the year have been, R. P. Thatcher, Geo. H. Lilley, W. C. Temple, Clifford R. Harris, James M. Merton, Edw. F. Tolman, L. B. Melville, B. H. Dillon, James Atkins, Cris C. Wais, Taylor Gleaves, W. P. Heineken, A. E. Childs, S. H. Harrison, A. C. Christensen, E. F. W. Gaskin, W. S. McKinney, C. H. Hurd, Theo. F. Scheffler, R. Deane Brooks, J. B. Pitchford, B. J. F. Bain, H. C. Moran, C. R. Diebold, Wm. Goodman, F. S. Greene, John Clark Finney.

Report of the Standing Committees of the Council

THE FINANCE COMMITTEE

The financial dealings of the Society have been larger than ever before in its history. We have conducted the sale of the property at 12 West 31st Street, receiving therefor $86 000 net, the investment of the Society in this property above the mortgage at the time of purchase, 1890, having been $27 000. This money has not yet been received into the possession of the Society as for legal reasons it has always stood in the name of the Mechanical Engineers Library Association and only recently has an order of the Court granted permission for the merger of the two associations and the transfer of this money to the Society which originally advanced it. The increase of activities of the Society has necessarily been accomplished by increased expense, but the benefits of the membership are commensurate.

The Standardization Committee has provided the Society with a complete new set of forms for the books, thus rendering regularly to the Chairman and to the Treasurer, weekly statements of the financial condition of the Society. These statements are also open at all times to the membership, and scrutiny of these books and records is encouraged.

During the period of assuming the obligations of the building of the Engineering Societies, the trust funds of the Society were reinvested in the mortgage for the land. With the receipt of the subscriptions to the Land and Building Fund, this money has been put back again into the several funds, Life Membership, Library Development, Weeks' Legacy etc., with interest at 4 per cent, the amount of the interest on the mortgage; consequently the financial condition of the Society is now stronger than ever, notwithstanding the increased activities.

The Society is discounting all bills when allowable and thus the financial management is most economically administered. In order to continue to do this, however, the membership should be prompt in the payment of dues and should take kindly to all of the letters from the Secretary, urging such payment.

During the year it is contemplated that advertising will be taken in the Proceedings, not to meet any present expenses, but to provide for the forward work of the Society and to enable it still further to develop the departments and scope of the Proceedings.

We submit report of audit of the financial condition of the Society by the Audit Company of New York.

EDW. F. SCHNUCK, J. WALDO SMITH, E. D. MEIER, *Chairman* ANSON W. BURCHARD ARTHUR M. WAITT	*Finance Committee*

THE AUDIT COMPANY OF NEW YORK
43 CEDAR STREET, NEW YORK

November 14, 1907

COLONEL E. D. MEIER, CHAIRMAN FINANCE COMMITTEE, THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, 29 WEST 39TH STREET, NEW YORK.

Dear Sir:

Agreeably to your request, we have audited the books and accounts of The American Society of Mechanical Engineers for the year ended September 30, 1907.

The results of this audit are presented, attached hereto, in three Exhibits, as follows:

Exhibit *A* Balance sheet, September 30, 1907;

Exhibi *B* Income and Expense Account for the year ended September 30, 1907;

Exhibit *C* Cash Working Fund. Statement of Cash Receipts and Disbursements, October 1, 1906, to September 30, 1907, inclusive.

These Exhibits are presented in the form as desired by your Committee for publication in the annual Transactions of the Society.

We certify that the balance sheet and related income and expense account, presented herewith, are true exhibits of the accounts, and correctly set forth the financial position of The American Society of Mechanical Engineers on September 30, 1907, and its operations for the period stated.

Very truly yours,

THE AUDIT COMPANY OF NEW YORK

(Signed) E. T. PERINE *President*
(Signed) F. C. RICHARDSON *Secretary*

EXHIBIT A

BALANCE SHEET, SEPTEMBER 30, 1907

ASSETS

Furniture and fixtures, book value	$1 867.82	
Library, book value	13 282.07	
Finished publications, plates, badges, etc., at cash	11 556.66	
Initiation fees and dues receivable	4 345.00	
Due for publications, badges, room rents, etc	9 692.89	
Due from land fund subscriptions, new building	4 578.00	
Deferred payments and charges	1 003.57	
Cash, trust funds	23 154.49	
Cash, available for current expenses	7 137.95	
Total assets		$76 618.45

LIABILITIES

Current accounts payable		$2 899.97	
Initiation fees and dues paid in advance		307.50	
Unexpended subscriptions to land fund, new building		2 623.24	
Trust fund reserves:			
Library	$6 700.04		
Weeks' legacy	62.59		
Initiation fees	10 470.09		
Life membership	342.57	17 575.29	
Total liabilities		$23 406.00	
Surplus, September 30, 1907		53 212.45	$76 618.45

EXHIBIT B

Income and Expense Account for the Year Ended September 30, 1907

INCOME

Membership dues	$48 264.25	
Membership initiation fees	1 050.62	
Sales of publications, badges, etc	24. 300.29	
Rentals	515.41	
Miscellaneous	2 331.36	
Total income		$76 461.93

EXPENSE PAYMENTS AND CHARGES:

Transactions, Volume 28, including estimated cost to complete	$8 400.20	
Office including salaries	19 059.65	
Meetings, Annual, Spring and Monthly	2 585.67	
Proceedings	11 487.98	
Membership development	2 415.31	
Membership lists and year book	2 232.35	
Library	1 499.30	
Rent and building operations	11 063.51	
Stores and sales department	12 849.81	
Miscellaneous	1 408.38	
Total expense payments and charges		$73 002.16
September 30, 1907, excess income for the fiscal year carried to surplus account		3 459.77
		$76 461.93

EXHIBIT C

Cash Working Fund—Statement of Cash Receipts and Disbursements, October 1, 1906 to September 30, 1907, Inclusive

RECEIPTS

Membership initiation fees and dues, rentals, sales of publications, badges, etc.	$61 287.29	
Membership initiation fees and dues paid in advance	307.50	
Transportation, spring meeting	210.40	
Sales of furniture and fixtures	342.68	
Trust funds	10 303.69	
Land fund subscriptions	64 241.57	
Total receipts		$136 693.13
October 1, 1906, cash balance		3 711.60
		$140 404.73

DISBURSEMENTS

Operations fiscal year 1905–1906	$6 445.07	
Operations fiscal year 1906–1907	62 273.96	
Reduction of land mortgage—new building	27 000.00	
Interest on land mortgage—new building	7 818.00	
Capital expenditures	9 507.75	
Total disbursements	$113 044.78	
Increase in savings bank deposits	20 222.00	
		$133 266.78
September 30, 1907, cash on hand and on deposit		7 137.95
		$140 404.73

THE MEETINGS COMMITTEE

We beg herewith to submit a report of the Meetings Committee to you for the past year, and in so doing would call attention to the fact that in former years the Society held only two meetings, the Annual and Spring meetings, with about four monthly reunions of a popular character at the official headquarters for the younger members of the Society. During the past year, however, professional meetings of the Society have been held regularly on the second Tuesday of each month from October to May, inclusive, excepting those months during which the Annual and Spring Meetings occurred. On several occasions eminent men from outside the Society were present and delivered very interesting addresses, such as those of Mr. Frederick P. Fish, President of the American Telephone and Telegraph Company on "The

Ethics of Trade Secrets," and the address of Brigadier General William Crozier, Chief of Ordnance, U. S. A., on the "Ordnance Department as an Engineering Organization." Your body has now placed these monthly professional meetings on the same basis as the Annual and Spring meetings, so that the papers presented thereat will be given equal consideration for publication in the Transactions, and in this respect the Society is now in uniform practice with the other national engineering associations. This gives the needed opportunity for presentation of all papers and on a greater variety of subjects than was possible with but two meetings; and we will also be able to have the papers more adequately discussed than heretofore. While the expenses of this Committee have been increased accordingly, it is felt that the Society and its members secure a generous return for the additional outlay.

The regular issue of the Proceedings is another activity in this line and is promoting a greater interest in the Society and making the membership at large feel closer to the work.

Upon the suggestion of this Committee, cards have been mailed to each member inquiring his preference as to subjects to be treated in the Proceedings and the meetings. This will enable the Committee to further meet the desires of the membership, and also enable it to select authorities or those who have given particular study to any questions which it may be desirable to have investigated or to ask for particular discussion on specific subjects. Still greater interest and value in the Proceedings is planned for the coming year, the aim being to make these publications a running record of mechanical engineering progress and of such usefulness that no engineer can afford to be without them.

GEO. R. HENDERSON *Chairman*	
A. E. FORSTALL	*Meetings*
CHARLES WHITING BAKER	*Committee*
WILLIS F. HALL	
L. R. POMEROY	

COMMITTEE ON LAND AND BUILDING FUND

The Committee hereby reports that, up to date, subscriptions have been received amounting to a total of about $71 000.

In order to complete the work we have undertaken we have yet to raise about $74 000.

STATEMENT OF THE LAND FUND ACCOUNTS

Fiscal Year ending October 1, 1907

Receipts		Disbursements			
Subscriptions secured by the Committee	$64 237.76	Dec. 24, 1904	For acquisition of property	$1 000.00	
Interest on same	488.70	May 22, 1905		8 000.00	
Amounts advanced out of Am. Soc. M. E. current funds to be subsequently returned to the Society	4 578.00	May 31, 1905		1 000.00	
		July 24, 1905		1 071.11	
		Jan. 15, 1906	Interest on mortgage	$4 000.00	
		June 1, 1906		2 000.00	
		Nov. 17, 1906		1 200.00	
		Dec. 21, 1906		3 870.00	
		June 29, 1907		3 240.00	21 [illegible].11
		June 30, 1906	Reduction of mortgage	60 000.00	
		Oct. 20, 1906		8 000.00	
		July 11, 1907		18 000.00	86 000.00
		Interest on advances			2 176.81
		Furnishings			4 [illegible].87
		Occupancy bldg., moving library, etc.			2 171.06
		Expenses of Committee			[illegible].47
		Balance cash on hand			2 580.04
	$69 304.40				$69 304.40

Balance cash on hand	$2 580.04	Amount of mortgage Oct. 1, 1907	$144 000.00
Unpaid subscriptions	7 425.00	Interest due Jan. 1, 1908	2 614.00
Amount received from M. E. L. A. applied Nov. 22 to reduction of mortgage	63 000.00		
Amount yet to be raised to discharge obligation	73 599.36		
	$146 614.00		$146 614.00

Of the subscriptions so far received about $15 500 has come from members subscribing as such; the balance of $55 500 from manufacturing concerns interested in mechanical engineering.

Members to the number of 218, or about 7 per cent of the total membership, have subscribed an average of about $71 each.

The total cost to the Society, of raising this $71 000 so far subscribed has been about 0.4 of one per cent.

In view of the present situation your Committee is of the opinion that very little money can at this time be obtained from manufacturing concerns, but we are considering what may be done among the membership and the best methods of doing that which may seem possible to be done.

Among other things we purpose to publish, in an early issue of the Proceedings, a fully detailed account of what has been done, giving the names of subscribers and the amount subscribed by each.

Herewith, we give in tabular form, a general statement of what has been and what is yet to be accomplished.

FRED J. MILLER
JAMES M. DODGE } *Committee*
R. C. MCKINNEY

THE PUBLICATION COMMITTEE

Your committee has received this year a larger number of papers than were received in any previous year of the Society's existence. Several of these papers are of special importance; the one by our Past President, Dr. F. W. Taylor, especially having attracted much attention from engineers all over the world. It has been extensively reprinted in engineering journals and has been translated into French, German and Russian.

About twice as much material has been published in our Proceedings and offered to the Publication Committee for the Transactions as was ever before considered. To meet this situation adequately and also to satisfy a long felt desire to have the work of the Society more logically presented, the Committee has arranged to have each volume of the Transactions cover the calendar year instead of the fiscal year. Formerly each volume covered the Annual Meeting of one administration and the Spring meeting of the following administration. Henceforth the work of one administration will appear in one volume. This, it is thought will assist the memory in locating papers and it has several manifest advantages.

It has been gratifying to the Committee to observe the extent to which the members have completed their files of back volumes; showing the appreciation of the Society at large of the valuable character of our Transactions.

Although the Meetings Committee receives the manuscripts and prepares them for presentation to the Society at its various meetings and for publication in the Proceedings the Society does not by that act obligate itself to publish this material in the Transactions. On the other hand it is distinctly of advantage to the Society to have another Committee pass upon this material and determine its value for permanent record.

Whereas nearly 2000 pages of material were published last year in the Proceedings only about half of that will be retained for the Transactions. This leads us to recommend that authors who are desirous of having their papers retained for the Transactions should be careful in preparing them to keep in mind brevity of statement so far as may be consistent with clearness and completeness

In coöperation with the Meetings Committee, the publication work of the Society is to be very much enhanced and attention will be given regularly to the including of symposiums or papers relating to all the principal divisions of engineering coming within the scope of this Society.

An interesting work now in hand is the publication of the Society history. This has been prepared by a special Committee consisting of Messrs. John E. Sweet, C. W. Hunt and H. H. Suplee, and will appear first as a serial in the Proceedings; one of the objects of this being to secure the benefit of suggestions and possible corrections by the membership. Afterward the history will be published in a single volume, uniform with the Transactions containing photogravures of all the Past-Presidents, Treasurers and Secretaries and of the several headquarters which the Society has occupied.

D. S. Jacobus *Chairman* C. J. H. Woodbury Fred J. Miller Walter B. Snow H. F. J. Porter	*Publication Committee*

THE MEMBERSHIP COMMITTEE

During the past year the Membership Committee has considered twice as many applications for membership as were ever before presented to it in one year. 503 applications, including 60 promotions, have been favorably reported. Many more applications were considered.

In addition to the above, there are 124 names on the ballot just closing and 199 applications pending. The present membership of the Society is the largest in its history, consisting of 16 honorary members, 2286 members, 324 associates and 740 juniors, a total of 3366. This is a significant indication of the progress of the Society.

The Council and members may be sure that the Membership Committee is most scrupulously scrutinizing the record of every applicant, and further, that no application is favorably passed that does not have references who are personally familiar with the engineering work of the applicant. We believe the Society was never so strict in this respect as now.

The members of the Committee feel that, while the labor of attending 16 protracted meetings has been great, they have been well repaid for their efforts.

Ira H. Woolson *Chairman*
Jesse M. Smith
Henry D. Hibbard
Charles R. Richards
Francis H. Stillman

Membership Committee

THE STANDARDIZATION COMMITTEE

The Standardization Committee has from the beginning of its work, eighteen months ago, taken the view that its first duty was to provide that the largest portion of the Secretary's time should be devoted to what may be called advance work. The object of your Committee therefore has been so to organize the office and routine work of the Society that it would go forward largely independent of the Secretary.

With this in view every effort has been made during the past year to study critically the various functions constituting the regular work of the Society. This has been done primarily with the idea of reducing them to written instructions which, incorporated into a book of standards, should act as a guide to the employees of the Society in the performance of their several duties. A large part of the field has been covered and the work is constantly being increased.

Through this study of methods many opportunities for improvements, involving both increased efficiency and lowered cost, naturally have presented themselves. In any work such as this, it is difficult to make any broad statement as to exact gains in efficiency or reductions in cost. That there have been both in large measure is shown by the reports of the various Standing Committees.

In this work your Committee has enjoyed the broadest spirit of coöperation from the various standing committees. We are also happy to be able to say that we have had the active assistance of every one of the office staff of the Society.

The standards which have been adopted are all on file in the Society's office and are open to the inspection of members. Any suggestions which may lead to their betterment will always be gladly entertained.

Frederick W. Taylor *Chairman* Frederick R. Hutton Fred J. Miller Calvin W. Rice	*Standardization Committee*

THE LIBRARY COMMITTEE

The Chairman of the Library Committee of The American Society of Mechanical Engineers desires to report to the Council at the present time that the property of the Library has been transferred from the house No. 12 West 31st Street to the upper floors of the Union Engineering Building without loss or injury, and that during the summer the books have been arranged in the new quarters, and the library opened in working order in association with the libraries of the Founder Societies.

It is realized that one of the most valuable features in the joint library lies in the bound files and current issues of the various technical journals. In order to facilitate the use of these it has been arranged to maintain a current subject index of the contents of these periodicals by clipping the items of the Engineering Index as it is issued monthly, these being mounted on cards and arranged in a card index, accessible to users of the library. This card index is kept up closely to date, supplementing the published volumes of the Engineering Index so that it may be used to direct anyone to the latest articles in the technical journals of America, England, and the Continent. Articles which have appeared since the issue of the latest volume of the Engineering Index will be found in the card index in the case in the library, and in by far the greater number of instances, the references thus indexed may be found on the shelves of the library, either in the bound volumes or in the current unbound numbers.

The librarians will gladly assist in finding any articles thus indexed, or in explaining the arrangement of the index.

The bound volumes of the Engineering Index are also on the shelves, available for reference upon request. This feature alone renders the library of especial value, both in finding the collected information upon any technical subject, or for investigating the state of any department of work, as in patent searches and the like.

In accordance with the authorization of the governing bodies of the three Founder Societies the chairmen of the three library committees hold meetings in conference for the general conduct of the library. This joint committee has adopted the following tentative rules for the conduct of its work:

That no questions shall be decided by majority votes of the three representatives of the three Societies, but that all decisions must be unanimous in order to become effective; dissent on the part of any one representative being sufficient to require a reference to the respective library committees, and ultimately, if necessary, to the governing bodies of the respective Societies, excepting as to matters regarding which the regular single representative is clothed with full powers.

That for the present all consideration of the question of a new organization for the administration of the three libraries, or of the appointment of any additional or general librarian, shall be postponed.

That the present arrangement, under which the three present Society librarians administer the three libraries, each under the supervision of her authorized Society representative, and in mutual coöperation as to matters of common interest or necessity, be continued.

That the reading room be open on all week-days, from 9 a. m. to 5. p. m. Only members of the three Founder Societies, and others duly introduced by the Secretary or other authorized officer of one of the Societies, will be permitted access to the alcoves or other spaces inside the rail.

That for the protection and convenience of members the Secretary of each Society, will, upon application, issue to any member of his Society in good standing a personal, non-transferable card, entitling him to the use of the libraries in the alcoves of the reading room. This card must be signed by the person receiving it, and surrendered at the desk at the time of its presentation. At every visit he must identify himself by signing his name in the registry.

That non-members may, in the two outer alcoves, receive and consult books for which they call at the desk; or they may, on similar application to one of the Secretaries secure special cards admitting them to the inner alcoves under similar restrictions.

The librarians shall have no discretion in the matter of allowing any catalogued pamphlet or volume to be taken from either of the libraries for any purpose, but shall decline to permit any such loan unless authorized in writing so to do by the Chairman of the Committee or the Secretary of the Society to which the pamphlet or volume belongs. But a duplicate may be thus loaned at the discretion of the librarian directly responsible.

W. J. JENKS, AMERICAN INSTITUTION OF ELECTRICAL ENGINEERS,
R. W. RAYMOND, AMERICAN INSTITUTION OF MINING ENGINEERS,
HENRY HARRISON SUPPLEE, THE AMERICAN SOCIETY MECHANICAL ENGINEERS.

Members are especially invited to visit the library when in New York, to use its facilities in every practicable manner, and to call upon the Secretary for cards entitling them to access to that portion of the room behind the desk and to the shelves.

AMBROSE SWASEY
GEORGE F. SWAIN
LEONARD WALDO
FREDERICK M. WHYTE
HENRY HARRISON SUPLEE, *Chairman*
Library Committee

At a recent conference of the three library committees it was decided to keep the library open until nine o'clock in the evening on all week days except public holidays. Considerable expense is assumed by this action, and the continuance of the policy will depend upon the number of persons who avail themselves of the privilege thus offered of making more extensive use of the library.

UNITED ENGINEERING SOCIETY REPORT OF TREASURER

JANUARY, 1, 1908

NEW YORK, February 15, 1908

To the Board of Trustees, United Engineering Society:

I beg to submit herewith the report of the Treasurer as of December 31, 1907.

Your attention is called to the fact that the resources and liabilities, receipts and disbursements statements cover all the financial transactions of the United Engineering Society from its organization up to December 31, 1907.

The income and expenses of operating the building during the whole operating period from December 15, 1906, to December 31, 1907, somewhat in excess of twelve months, are given.

Included in the expenses, amounting in all to $52 647.11, will be found an item entitled "Building Equipment"—(construction account). The expenditures under this item were not made for the operating expenses of the building, but represent a construction account, properly speaking, covering expenditures for furnishings and equipment of the building. The Founders' Agreement specifically provides for this class of expenditure under the provision that the Founders' Societies shall each be liable for a charge not to exceed $200 000 of principal, which shall include the land and building completed and ready for occupancy, together with the "Furnishings, equipment and personal property therein."

Certain details of equipment are yet to be supplied, and it is proposed in the near future to call upon the Founders' Societies for an assessment on their respective land and building funds to cover this item of building equipment. Such action would enable the item of $10 039.85 to be transferred to the income account and reduce correspondingly the assessment which it would be necessary to make on the Founders' Societies to cover the operating expenses for 1908.

The actual operating expenses for the period December 15, 1906, to December 31, 1907, have been		$33 126.41
or including furniture and fixtures, amounting to		1 307.41
we have a total operating cost of the building for the above period of		$34 433.82
This includes an expenditure for telephone service of	$1 174.76	
for which we are reimbursed by the occupants of the building, and also the cost of insurance premium for two years, only half of which should be charged to the 1907 operating account	1 087.24	
There should, therefore, be deducted from the 1907 operating account a total of		$2 262.00
making the actual net cost of operating the building for the period of twelve and one-half months, including repairs and renewals, but exclusive of depreciation and reserve allowance		$32 171.82
Or, for the year—exactly 12 months—	$30 884.94	

It will also be noted that in compliance with the provisions of the Founders' Agreement (Article 68) the Trustees have set aside, as a special fund to cover depreciation and reserve for 1907, an amount of $5000.

In the report submitted by Messrs. C. F. Scott, B. J. Arnold and Dr. S. S. Wheeler, under date of January 29, 1904, which was transmitted to the Founders' Societies at the time, it was estimated that the cost of operating the building would be approximately $27 000.39, exclusive of repairs and renewals and depreciation, which were estimated together at $2961 making a total then estimated of $30 000.

Attention is called to the fact that we have still available unoccupied space to the extent of the equivalent of one entire office floor, which, if occupied, would produce an increased revenue through assessments of approximately $11 000 per year.

While each Founder Society occupies and is assessed for one whole floor, some of this space would be available for other tenants should all the other office space become occupied.

The assessments paid by each of the Founders' Societies occupying one entire office floor were $10 000 per year. In addition to this each Founder Society bears its burden of interest charges amounting annually to $7000, a total cost of $17 000, exclusive of charges for any occupancy of the auditorium or meeting rooms.

At the present rate of assessments for office space, the Associate Societies pay for similar accommodations at the rate of only $8868 per year.

Even if it be assumed that the Founders' Societies alone should bear the pro-rated charges for the occupancy of the library floors, their total assessments, on the basis of the Associates' assessment, should be only $14 780 per year, instead of $17 000, the amount they have actually paid the past year.

It should be noted that many of the Associate Societies did not move into their quarters until considerably after January 1, 1907, and the Income Account does not, therefore, represent a full year of occupancy.

It will be seen, therefore, that as long as there is unoccupied space in the building the burden which the Founders' Societies will have to bear will be considerably in excess of the corresponding assessments which are being charged to the Associate Societies. Attention is also called to the comparatively small use of the auditorium as shown in the report of the building superintendent.

It is suggested that further efforts be made to induce other Societies to occupy the office space still available, and to secure a larger utilization of the auditorium and meeting rooms. When such larger utilization shall be made of the exceptional facilities offered by our building, the burden of expense which the Founders' Societies are now called upon to bear will be notably reduced and the cost to them of their office facilities will be not greater than the rental of similar office space elsewhere, while the advantages accruing to each Society from joint occupancy of the building will be of inestimable benefit to every member.

Respectfully submitted

[Signed] J. W. Lieb, Jr.

Treasurer

UNITED ENGINEERING SOCIETY

Balance Sheet, January 1, 1908

ASSETS

Real estate, land	$540 000.00	
Real state, building	1 050 000.00	
Building equipment (construction account)	10 039.85	
Furniture and fixtures	1 307.41	
Accounts receivable	1 950.00	
Petty cash	500.00	
Cash, bank balance	6 507.87	
		$1 610 305.13

LIABILITIES

Joint balance of mortgage (land)	$292 000.00	
A. I. E. E. payments in liquidation of mortgage on land	99 000.00	
A. S M. E. payments in liquidation of mortgage on land	99 000.00	
A. I. M. E. payments in liquidation of mortgage on land	50 000.00	
A. I. E. E. equity in building	350 000.00	
A. S. M. E. equity in building	350 000.00	
A. I. M. E. equity in building	350 000.00	
Building equipment (construction account)	10 039.85	
Furniture and fixtures	1 307.41	
Depreciation and reserve fund	5 000.00	
Balance cash and accounts receivable	3 173.44	
Accounts payable	784.43	
		$1 610 305.13

UNITED ENGINEERING SOCIETY

Statement of Receipts and Disbursements up to December 31, 1907

RECEIPTS

Preliminary founders assessment	$24 000.00	
Account principal of mortgage	248 000.00	
Account interest of mortgage	47 098.86	
		$319 098.86
Refund account organization expense	4 696.18	
Refund account interest	46.55	
Refund account insurance	387.50	
Donation account dedication exercises	403.25	
		5 533.48
Assessment founders	29 999.97	
Assessment associates (offices)	9 134.22	
Assessment miscellaneous (meetings)	2 904.25	
Telephone and miscellaneous receipts	1 459.46	
		43 497.90
		$368 130.24

DISBURSEMENTS

Account principal of mortgage	$248 000.00	
Account interest on mortgage	58 798.86	
Organization expense	10 634.27	
		$317 433.13
Building equipment (construction account)	10 039.85	
Furniture and fixtures	1 307.41	
		11 347.26
Operating account (cash disbursements)	28 112.53	
Stationary and printing	1 890.26	
Insurance (two years)	2 339.19	
		32 341.98
Balance, cash in bank	6 507.87	
Petty cash	500.00	
		7 007.87
		$368 130.24

Operating income and expenses. Operating period December 15, 1906, to December 31, 1907

INCOME

Cash balance December 31, 1906	$7 199.21	
Assessment founders	29 999.97	
Assessment associates (offices)	9 408.55	
Assessment miscellaneous (meetings)	4 041.75	
Telephone and operating	1 997.63	
		$52 647.11

EXPENDITURES

Operating account	28 896.96		
Stationery and printing	1 890.26		
Insurance	2 339.19		
Total operating expenses		$33 126.41	
Building equipment (construction account)		10 039.85	
Furniture and fixtures		1 307.41	
Depreciation and reserve fund		5 000.00	
Balance (surplus on hand)		3 173.44	
			$52 647.11

No. 1164

THE MECHANICAL ENGINEER AND THE FUNCTION OF THE ENGINEERING SOCIETY

President's Address 1907

By PROF. F. R. HUTTON, E.M., Ph.D., Sc.D., NEW YORK

The convening of The American Society of Mechanical Engineers for its Annual Meeting in the splendid building devoted to the needs and uses of such a Society and for the first time in such surroundings makes it seem fitting that the opening address of the meeting should consider the duty and function of the engineering society in its relation to the profession which underlies it. The speaker takes special pleasure in availing himself of this opportunity by reason of the many years of his service to such a Society and of the close touch permitted to him for this reason with the problems which the topic presents.

2 It would be an attractive possibility to consider the wide range of the Engineering Societies as they are grouped under the roof of this Engineering Building, and to discuss their functions with respect both to their own specialties and to the profession as a whole. This would open up the possibilities of the building and the significance of it as a gift to our profession in a way which would be both stimulating and suggestive; and would present the greatness of the thought in the mind of its donor in a way to make it remembered. But the limitations in space and time and the proprieties of the case make it appear fitting to confine consideration to the one field of the Mechanical Engineer, and to the function of The American Society which bears his name. This simplifies the questions into two: What is the mechanical engineer at the opening of the twentieth century; and, what are the duties and functions of an American Society of Mechanical Engineers to that branch of the profession? This latter logically divides into two sections; the duty of the Society to those without its membership; and the duty of the Society to those enrolled within it.

Presented at the New York Meeting (December 1907) of The American Society of Mechanical Engineers, and forming part of Volume 29 of the Transactions.

3 In seeking a defensible definition of the mechanical engineer in these days, which are those of specialization on the one hand and of broadening scope upon the other, there are several courses open. The first and obvious one is to rest upon authority and inheritance and to follow recorded standards which have some vogue or acceptance. The second is to gain definiteness of thought by differentiating the mechanical engineer from other specialists by noting what lines of professional activity are *not* his; and the third will be to scrutinize the list of membership in the Society and so dividing the members into groups to generalize therefrom as to what the man is doing who is or claims to be a mechanical engineer.

4 In turning to the historical definition, or that which has its authority from long usage, the stately language of Tredgold of England always claims first place as of right. At a meeting of the Council of the Institution of Civil Engineers of Great Britain on December 29, 1827, Mr. Tredgold, Honorary Member of the Institution, was requested by resolution to "give a description of what a Civil Engineer is," in order that this description might be embodied in the petition for a charter for such a body. Mr. Tredgold's historic definition is:

5 "Civil Engineering is the art of directing the great sources of power in Nature for the use and convenience of man." He amplifies this by adding that it is a practical application of the most important principles of natural law, and has among its objects that of improving the means of production and of traffic for external and internal trade, such applications being directed to the construction and management of roads, bridges, railroads, aqueducts, canals, river navigation, docks and store houses, ports, harbors, breakwaters, moles and lighthouses. He includes also the protection of property from injury by natural forces, as in the defense of tracts of land from encroachments by sea or rivers: the direction of streams and rivers for use either as powers to work machines or as supplies for towns or for irrigation, as well as the removal of noxious accumulations as by drainage. He touches also upon navigation by artificial power for the purposes of commerce, and adds that the scope of utility of engineering will be increased with every discovery in natural law and physics, and its resources with every invention in mechanical and chemical art. The Charter of the Institution repeats the Tredgold wording, and describes the profession of the civil engineer as "the art of directing the great sources of power in nature for the use and convenience of man, as the means of production and of traffic in states both for external and internal trade as applied in the construction of roads and bridges, aqueducts, canals, river navigation and docks for internal intercourse

and exchange and in the construction and adaptation of machinery and in the drainage of cities and towns."

6 In comment upon this definition it may be observed:

a It should receive the respectful homage which is due to a great achievement. Its breadth and comprehensiveness show us how great was the man who created it, and so early in our industrial history. By suitably extending the meaning of its terms and by reading into them the fuller significances of the later years, the definition is still defensible for what it can be made to cover. We have not outgrown it yet, by any means.

b It should be regarded as a definition of engineering in its broad and comprehensive sense, and should not be used to apply only to that specialized department of the profession to which in America the term civil engineering is applied in education and in popular use. What Mr. Tredgold meant was the profession of the civilian practitioner of engineering, as distinguished from the military engineer, the latter being concerned with the special problems of the fortress and the work of the army. The civilian and the military engineer have much the same problems in any case, and the military engineer in the field of ordnance becomes perforce a mechanical engineer of high order,[1] but the purpose of the Tredgold definition was to form the basis of a charter for an organization of civilians as differentiated from employees of the British Government in their own engineering field; and the qualifying word applied to the engineer should be so understood in the light of its purpose.

c In the third place it should be noted that this definition of engineering as practised by the civilian was given in the infancy or at the birth of the modern industrial epoch in which we are now living. This constitutes an element of the admiration we must feel for the greatness of its creator, that under these conditions he should have seen so far; but the fact is also responsible for the limitations which are suggested by it and which must be removed in the light of our present clearer vision. The year 1827 was two years in advance of the competition at Rainhill where Stephenson won fame for the solution of the motive

[1] See paper by Brigadier General William Crozier, p. 65, vol. 29.

power problem of the railway: the first power driven steamboats on the Thames had been struggling against the tides only since 1813, and Dr. Dionysius Lardner had convinced all conservatives that the consumption of fuel as the standard then existed would preclude all successful working of long distance marine service such as across the Atlantic Ocean or around the Cape. The machine tool was still a small thing, whose tools were held by hand to the work to be done. Engineers were highly pleased when the fit of the engine-piston in the bore of the cylinder was so close that "at no point in its circumference or traverse could you drop a shilling through the space between the two." The mining of England while important relatively was yet limited for lack of shaft-machinery and was largely or entirely carried on by mine-bosses of experience. Faraday had yet four years to labor before he made his historic discovery of the electric current induced by motion before the pole of the magnet. The metallurgist and chemical engineer could only come into being when the needs of a community, built upon industrial production with cheap power at its base, should have called for him. What did exist were mills driven by water-power: the iron works built upon the puddling and rolling processes originated by Henry Cort, and the achievements of Boulton and Watt in respect to stationary steam engine Nasmyth with the steam hammer and the large machine tool were still in the future; but most of all and most significant of all from the present point of view, the idea of manufacturing or production upon a large scale, in factories or shops where great groups of productive machinery were gathered together to be served by a common source of mechanical power had not yet been born. The industrial community or civilization made possible and present by the combined achievement of the physicist, the mechanical engineer and the electrical engineer, in whose power house and from it are liberated, generated and transmitted the vast volumes now in use of industrial energy is truly dependent upon the powers of nature controlled and directed by engineers. The implication is however that these forces of nature are in existence and active and are awaiting control and direction. The definition is silent upon that group of engineers concerned with the liberation, the generation and the transmission of forces which are potential and are not realized in nature until in accordance with natural law some engineer has caused them to appear.

d Again, it is only by a great stretching of the inclusive character of terms, that the expression "powers of nature" can be made to include the forces which are economic or social or psychological in their application, and which come into play for control and direction when production on a large scale is under consideration, and large numbers of human beings become the organs or implements of the factory as a tool for production. The aggregation of power, machinery and producers is a unit; it is to be created, organized and operated for an end. By whom? The ordinary commercial or financial or business training alone is not adequate for proper direction and control: the learned professions of law, medicine or divinity are not suggested for the purpose; but as the engineer has created the plant in its physical aspects, he would seem the proper one to operate it in its industrial functions. The engineer has therefore become an economic factor as he was not conceived to be in that earlier day. The energies directed and controlled by such an engineer may only be included within the "powers of nature" by an effort which strains their meaning to the breaking point in unfriendly hands: he is yet a director or controller of forces, and of no insignificant type.

e The inclusion of the powers of nature within the scope of the elements of the profession of engineering carries with it the utilizing of the resisting forces created in the materials of engineering when such powers are exerted to deform them. Engineering, therefore, correctly covers the creation of structures to resist the dynamic action of forces, meeting by the principles of statics the impact or action of impressed energy. The definition might properly be extended, therefore, to cover both the adaptation of the physical properties of the materials of nature or manufacture to the withstanding of stress, and the direction and control of forces.

f Finally, he who commits himself to the splendid Tredgold definition must take its alleged defect with its excellency. It is that it includes as engineers not alone those who create and install apparatus to control and use the powers of nature, but those also who direct and control the machines or apparatus when created and installed. This will include those who may be called "coördinators of design," who take the boilers, engines, dynamos, condensing apparatus, piping and pumps which are on the market, and combine these into a consistent whole. They have not designed any of the units themselves, or created a new machine, but they have created a power house, and are utilizing the powers of nature for the use and convenience of man. Somewhat under the same category is he who receives the finished power house with all its units from the foregoing type of engineer and his allies, the contractors who have done the construction work, and is then and thereafter entrusted with this upkeep, repair and continuous operation. Such a man also directs and controls the powers of nature, albeit on a less exalted plane than the creator or designer or the coördinator. There are those who would make the coördinator appear as a mere purchasing agent, and the operator as a mere craftsman, and neither an engineer. I cannot agree with them, believing that their function calls for skill and acquirement of a high order. The historic definition unquestionably provides for them.

g If the writer may modestly put forward a suggestion for a revision of the historic definition, he would word it: "The Engineer is he who by science and by art so adapts and applies the physical properties of matter and so controls and directs the forces which act through them as to serve the use and convenience of man, and to advance his economic and material welfare.

h It may be of interest to add that the accepted dictionaries of the day, the Century and Standard, define the engineer as one versed or skilled in the principles and practice of any department or branch of engineering, deriving the word from older forms which means he who makes or uses an engine. Engineering is further explained as the science and art of making, building, or using machines and engines; or of designing and constructing public works or the like, requiring special knowledge of materials, machinery and the laws and principles of mechanics. Both give as a secondary meaning, one who runs or manages an engine. Both the French and the Germans avoid this latter double use of the word by calling the practitioner of this sort of engineering a *machiniste* or a *maschinist*. The French also have the word *mechanicien*. The dictionary phrases are a little hard on the mining engineer, for example, who is scarcely visible in the description.

This leads up naturally to the differentiation of the mechanical engineer from those versed and skilled in other branches.

7 In making the following classification it is obvious that unanimity cannot be secured from all as respects the number of branches to be recognized. With this apology and for the purpose in hand there are at least thirteen:

a The mining engineer and his close ally, the metallurgical engineer, is concerned with the discovery and the winning and extraction from the earth of its buried treasures of oil, fuel and rock. He touches the geologist and mineralogist on one side of his functions, and the chemist upon the other. Midway he allies himself to the mechanical engineer for the power to overcome his resistances and to the electrical engineer for its convenient transmission to the working point. If he concentrates his ore after winning it from the earth he calls again for his machinery upon the mechanical engineer. His profession passes at one limit into the craft of the quarryman; and the other, he calls on the art of the civil engineer for his tunnels and for his shafts; or the tunneling and shaft work of the civil engineer is done for him by the miner. The metallurgical engineer who transforms the crude ore into marketable metal or into the merchant form or structural shape is allied to the chemist upon the one side for his processes and to the mechanical engineer upon the other for his machinery. The electrical engineer is more and more furnishing him the energy for conversion by heat through electrical channels, the mechanical engineer furnishing the latter his power. The mining engineer may be both miner and metallurgist. The iron and steel metallurgist is usually a mechanical engineer.

b The electrical engineer is primarily entrusted with the transformation of mechanical or chemical energy into electric form, and its transmission in that form to the point of use, where it will be again converted into some other shape. The electrical engineer has made his own the questions of generating such electric energy for the solution of the problems of lighting, transportation of passengers by railway, and communication by telegraph and telephone. He touches the physicist in the realm outside his applications of science, and has the mechanical or hydraulic engineer next to him to supply mechanical energy to his generator, and the mechanical engineer beyond him, where his energy drives the tool, or operates the pump or the elevator. Where his energy is made to appear as high heat, he serves the metallurgist, the chemical engineer; where it appears as low heat or as light, he serves the individual members of the community directly, as he does in the problem of communicating speech. His field is very definite.

c The naval engineer and marine architect is a specialized mechanical and structural engineer. His hull is a truss unsymmetrically loaded and variably supported: his motive power a definite yet widely diversified problem. He covers in addition a wide range of special problems when his vessel is also a club house or hotel, on the one hand, or a powerful fighting machine upon the other.

d The military engineer must cover both the defensive and the offensive department of his avocation. On the one side he is a structural engineer, and the problems of effective transportation enter his field, which he therefore shares with what is usually called the civil engineer. On the side of attack, the problems of ordnance both for its construction and for its operation take him into the field of the mechanical engineer and electrical engineer, and his problems touch those of the physicist and the chemist and the mathematician on the research and theoretical side. In fact the problems of the military engineer are probably those in which the solutions offered by pure theory can be most directly utilized of any presented to the engineers, inasmuch as questions of cost and of financing are usually secondary for him. If the result is worth attaining at all, the national governments will always be among the most lavish spenders.

e The chemical engineer is a new applicant at the door of professional recognition in certain quarters. He is the engineer in charge of production or manufacture where the process or the product, or both, are chiefly or entirely dependent upon the theories and practice of chemistry. He shares his field with the metallurgical engineer as respects the manufacture of metals; he is a mechanical engineer as soon as the plant becomes large enough to warrant the application of power and machinery to the mechanical handling of his product. Gas-plants, sugar and oil refineries and the straight chemical manufacturing corporations call for such a man, whatever his designation. It would appear, however, that the normal tendency of growth and development in this field will be toward the utilization of two types of man. The one will be the chemist and the scientist; the other will be the mechanical engineer and executive. It may easily happen that in the days of small things the two sets of duties may devolve upon one man; later on it will be found that the best qualifications for both duties will not be found in one individual, and the volume of duty becomes too great for one man to be effective in both. When separated, the cleavage will be along the above lines.

f The sanitary engineer is a specialist in hydraulic engineering in the applications of water supply and drainage as means to secure the well being of the community as respects its public health. His field expands from that of the wise precautions respecting the piping of the individual house, where he touches the craftsmanship of the plumber, up to the broadest problems of sewage disposal and utilization, and the healthful supply of potable water for cities, free from bacterial or inorganic pollution at its source or in transit. His co-workers are the bacteriologist and the physician. It would seem more serviceable however for the purpose in hand to group such men with what are hereafter to be called the civil engineers.

g The heating and ventilating engineers, making a specialty of the sanitary requirements of enclosed houses as respects their fresh and tempered air supply, are really sanitary engineers, having however an outlook and a relation to mechanical engineering in the appliances of their function rather than toward civil engineering.

h The refrigerating engineer is concerned with the transformation of mechanical or heat energy so as to lower the amount of such intrinsic energy in any material or space. He is most unassailably a mechanical engineer.

i The hydraulic engineer is of two groups. The one type concerned with the problems of the river or canal for navigation or for power with the dam and its accompanying details of water ways and controlling gate houses and sluices; and with the gravity storage and distribution by mains of the city water supply has plainly his outlook toward civil engineering. The other type, concerned with the water motor and its attached machinery for its operation; with the mechanical handling of water for city use or for power in industry, the designer of pumps and hydraulic utilization machinery has his outlook equally definite upon the field of the mechanical engineer. The future is likely to see this differentiation emphasized, the one class calling himself a civil and hydraulic engineer, and the other class a mechanical and hydraulic engineer.

j The gas engineer has two sets of problems: The one is the intra-mural manufacture and storage of his product, where his functions are those of the chemical manufacturer, and he should be both chemical and mechanical engineer; the other is the distribution problem for whose solution is required the skill and knowledge of a type which is unnamed, but which logically in parallel with the hydraulic engineer above, should be called the pneumatic (or gas) engineer. Industry has never stopped to be logical however, and the pneumatic engineer should be a name to suppress. The future will doubtless widen the scope of the gas engineer to cover the plants which make and use fuel gas for power and heating in units not so large as those on the municipal scale now in evidence for lighting mainly. Such creators and engineers for heat and power will plainly belong in the mechanical field.

k There is no recognized group of engineers of transportation, or transportation engineers. Such a group obviously exists, however, whether or not the name is attached to an organization inclusive of all, or is in general use. Such are the engineers of motive power on the steam railways, with the master mechanics and the signal engineers and the operative class on locomotives; such are the street railway engineers; the car builders; the maintenance-of-way engineers, the bridge engineers, the engineers of floating equipment. From the bottom of the rail upwards, these have their outlook on mechanical or electrical engineering; from the bottom of the rail downward, upon civil engineering.

8 The foregoing grouping does not claim to be exhaustive nor inclusive of all subdivisions of engineers even so far as it has gone. The current activities of the Engineering Building reveal bodies of municipal engineers, of illuminating engineers, of engineers concerned in fire protection, and many others. But the purpose has been to clear the way for the separation of the two most closely allied in function and service, the civil and the mechanical engineer. The civil engineer is confessedly differentiated from the electrical and from the mining engineer: he has been more and more utilizing the achievements of the mechanical engineer, or the latter has been invading the former field of the civil engineer.

9 It is plain that to the civil engineer belong as of right all problems relating to the canal, the lock, the river, the harbor, the dock, the sea-wall, the break-water, the highway, the aqueduct, the bridge, the viaduct, the retaining wall, the permanent way of the railway below the foot of the rail. He also has nearly the whole of the municipal problem in streets, sewage, distribution of water; the location of railways, with geodetic and other surveying are his. He has the foundation of structures in any event, but may have to share the roof and the skeleton steel frame with other specializations Tunneling is usually done by civil engineers, although it was originally a mining engineer's prerogative.

10 To the mechanical engineer on the other hand, belong as undoubtedly, and as of right the problems of the generation of power in power houses and power plants, and its transmission to the operative point unless this latter is done by electric means. It is a fair question, however, when the electrical engineer simply transmits energy generated by the mechanical engineer and utilized in industry by the latter after transmission, whether the electrical engineer as an engineer of transmission is not for the time a mechanical engineer. If the transmission were by compressed air on a sufficient scale, calling for a specialist in that field, would such a man be called a compressed-air engineer?

11 It is also plain that to the mechanical engineer belong all design, creation and manufacture of tools and machinery. This makes him therefore the natural administrator or executive of the production processes involving the use of machinery in factories and mills, and it is here that he finds his broadest scope and widest opportunity, as will be further demonstrated hereafter. As creator of

machinery he will be a draftsman or designer of a producing plant: as operator of the plant considered as a tool for production, he will be a general manager or superintendent, or will perform these functions as owner or as president, vice-president, agent, secretary or treasurer. As a producer of power, the railway will make the mechanical engineer their superintendent of motive power, and the rail and joint become also responsibilities of his; as administrator of men and machinery, he becomes master mechanic of the railway and more and more such engineers are chosen to be general superintendents. The automobile or motor vehicle engineer is of course a mechanical engineer. From his knowledge and special training he becomes the inspector and tester for all departments of mechanical production.

12 But this relation of engineer of production borne by the mechanical engineer is at the bottom of very notable developments of progress. As the scale of production increases with the aggregation of capital invested, the permanence of the business becomes inseparably bound up with the satisfactory quality of its output. Hence there grows a system of business in which the reputation of the producer becomes a factor compelling him to satisfy the buyer as respects the engineering excellence of his purchase; and it becomes possible for the contract between the two to be based upon the specifications created by the producer or seller, and not by the engineer of the buyer. This makes for cheapness and promptness of production and delivery, since standard articles become possible and frequent. It is a system lying largely at the base of the American success in competition in foreign markets, as it differentiates our practice from that of England for example. It points to a narrowing of the scope of the office of consulting practitioner as compared with the widening scope of the manufacturing engineer. It marks a broad differentiation between the civil and the mechanical engineer, in that the former never or very rarely attaches himself to a producing interest. He serves a municipality, a corporation or an individual always as a representative of their interests as a buyer or user. It is his function to see that specifications unfriendly in intent to the interests of the seller are carried out by the latter. The engineer of production is called on to originate his specifications and to enforce them in production, in order that the guarantee of quality and of economy in use may both be satisfactory to such user. The entire point of view of the two types is radically diverse.

13 This achievement of the manufacturing or production engineer gives significance to the work of the considerable group of mechanical engineers, who have been earlier designated as "co-ordinators of design." These are they who take the satisfactory designs or creations of

the producing engineer and combine such elements into a unit for some industrial purpose. It would be foolish and unwise for such men to pass by existing standards upon the market and create special designs of their own. These latter would not only be more costly to pay for, but their delivery would be slower, and problems of repair and replacement be many times more difficult, costly, and delaying. Their creative function as engineers however is different from that of the producing engineer proper; yet to succeed demands the same faculty of critical selection and of adaptation of means to ends upon a basis of sound science which distinguishes the other group. To them belong those engineers of operation and development of existing plants, who rarely create, but who skilfully select and adopt and combine.

14 This economic condition also has given rise to a group of engineers properly mechanical, who are directly and productively related to the producing corporations as their representatives in their selling organization over a large territory. It is unfortunate that these men of professional standing and of engineering qualification should be so often called "Sales Managers." It is their duty to act exactly as the coördinator of design does in his office, and secure for the intending purchaser an engineering solution for his needs which shall be satisfactory to him. His value to the producing corporation is inevitably measured by the number of contracts which he brings them: his value to his clients is measured by the engineering value of the specifications upon which such contract is based. The mere salesman could not perform the duty of the case, unless the buyer were protected by a consulting engineer. It is economically to be preferred as above, to have the specification emanate from the seller.

15 And finally, the group of engineers of production must include the industrial engineers who are organizers of men or departments or works as tools of production. These men are not creators of visible machines embodied in steel or iron, which perform material functions before our eyes. Yet are they creators of power and directors of forces under the fundamental definition. They may do this as independent consulting engineers from an office relation; or they may be continuously employed for this purpose by one producing concern. In either case their successful achievement is the same in principle and in result as that of him who devises a new automatic machine by which output is increased and cost of production cut down.

16 The final criterion or touch-stone for all these claims for the scope and function of the mechanical engineer must be the answer and attitude of the profession itself. The American Society of Mechanical

allegiance to other bodies closely related to their specialty. Their membership in this Society is an extra adherence for reasons of greater or less personal weight.

l The professor or teacher of engineering 185. This is a large group, probably larger than in any other similar body, and for the reason that through the Middle West the state college is very strong in its industrial and mechanical departments, and its officers desire touch with the work and personnel of the producing enterprises of the country. Comment or criticism by such users of the university product will be most helpful to the instructors of every grade.

m The draftsman and designer 115.

n The local manager, or district representative engineer of the manufacturer 153.

o The shop executive, superintendent, department manager, assistant superintendent in large works 338.

p The producer or manufacturer, owner of the plant, president, vice-president, or executive officer of the corporation, and the mechanical engineer of such producing bodies 966. The subdivision of the last four groups is for the purpose of showing the widespread significance of the contention of this paper as to the economic significance of the mechanical engineer; if all four were grouped into one, they would include 1572 or practically half of the total membership.

q The last group is the office practitioner or independent consulting engineer not officially or visibly related to a producing enterprise, 493. This includes doubtless many who might have been included in one of the other classes previous to Class *l*. It covers the coördinators of design, who are often also contractors, probably many patent men, hydraulic engineers and local managing experts, which if placed under the other headings would still further reduce the size of this class. The broadened scope and opportunity for doing great work which are presented by the large aggregations of capital in the producing enterprises, as compared with the difficulty of great engineering achievement with little capital, are continually attracting men from this group into Class *n*, *o*, and *p*.

r Presenting these facts in tabular summary:

	Group Name	Numbers		Percentage	
a	The unclassified	306		10.3	
b	The army and navy	11		0.4	
	and marine	18		0.6	
c	The hydraulic	12		0.4	
d	Patents	25		0.8	
e	Journalists	30		1.0	
f	Mining and metallurgy	31		1.0	
g	Engineering contractor	48		1.6	
h	Testing and inspecting	49		1.6	
i	Operating engineer	55		1.8	
j	Locomotive and railway	57		1.9	
k	Electrical engineer	65		2.2	
l	Professor and teacher	185		6.3	
m	Draftsman and designer	115		4.0	
n	Local manager	153		5.2	
o	Shop executive	338	1572	11.8	53.6
p	The manufacturer	966		32.6	
q	Office practitioner	493		16.5	
	Total	2957		100.0	

19 There would seem therefore a good ground for defending a twentieth century Tredgold who should define or describe the mechanical engineer of his period: "The Mechanical Engineer is one who by science and by art so adapts and applies the physical properties of matter and so controls the forces which act through them as to serve the use and convenience of man and to advance his economic and material welfare. He does this mainly by storing and liberating motor energy through machines and apparatus which he designs and installs and operates for the purpose of fostering and developing the processes of industrial production which use and require such power upon a large scale."

20 The foregoing discussion draws after it as in its wake a group of other interesting questions; or to change the figure, a number of open doors to other topics appear as we follow the guide along the corridor. Among these for example, is the historical one, as to how the engineer came to be the central figure which he is to day. In the earliest times the patriarch with knowledge of safe and desirable pasturage for the flocks was the central figure; later, the war-lord was king; he in turn gave way to monkish priest as supreme center, and after a recrudescence of the warrior and conqueror we are now planning armament and training men and scheming policies to secure peace which shall enable the production engineer to do his best work and with the least waste. As early as the legend of King Solomon is the claim of the tool maker, and the mechanical engineer of today is the

heir of the functions of the tool maker on the largest scale. Again, the educational significance of the definition is most important. We have derived our standards in the technical schools from the requirements of the historic Military Academy at West Point. This in turn inherited the policies and practice of the European governmental schools for engineers. We have borrowed also from France and Germany directly. Very close to the heart of such standards lies the devotion to the highest mathematics both as a discipline for the mind and character, as a preliminary training for study in statics and dynamics, and as a means of separating the qualified and the assiduous from the incompetent and lazy. But if fifty per cent or more of the graduates are going to find their life work along lines which make no call for extended use of the higher mathematics; if by using, as the separating sieve a device which lets through many men of a mentality ill adjusted to the demands of practical life in production, and which holds back many men who lack facility in working with symbols of quantity because they can better handle the larger problems of the quantities themselves, then it is a fair question whether the splendid discipline of higher mathematics has not been bought at too high a price? Could we not get a better prepared man for his life work if the same discipline and the same selective process for the fit had been secured by more and better physics and more and better chemistry and more economics, even if these were bought at the price of some mathematics?

21 But my time and the occasion demand that we pass at once to the second phase of the thought of the evening. What can or may the Engineering Society made up of Mechanical Engineers as above, do for the profession? What are its duties and functions? It is plain that these are in two directions; its service to the members within it, its duty to those outside of it. Some duties and service will be the same to those within and without; in others there will be differences.

22 Taking up first the service to the members within it, the Society can do at least eight things:

First it serves by its existence. The fact that there is such a body at all is a token of its strength. For it means that there are three thousand men and over, who with all their diversities have yet a common dependence upon law and principle, and who are pursuing a common aim. The courage and cheer which comes from association and comradeship is a service. The wave which buffets and all but overturns the struggling skiff beats fruitlessly for harm against the tonnage of the ocean liner. Steadily the great aggregation plows her way through stresses which would be fatal to the same totals if subdivided into units. The whole has a strength which is even greater than the sum of the strength of all its parts.

23 This benefit may be regarded as one of the most widespread that the Society offers. It is independent of residence location and is reaped by the foreign member as well as by the dweller near the centers. In fact it is more significant to the lonely dweller than to the metropolitan member. It remains even when the other returns to the subscriber to the Society in publications, in association and in meetings either lessen or cease. He may well keep on paying dues (perhaps reduced in amount) after the value of papers and meetings become no longer worth while.

24 The value of this return is greater in proportion as the Society is larger, so long as its quality is maintained. This is the argument for the national and international body as contrasted with the local body or section. Any policy or step which gives occasion rightly to charge a tendency for a national body to localize is an invasion of opportunity and value. The local body may offer some advantages of its own. It does not offer this one. A localizing of an office organization or of a printing contract or even of a library is not a localizing of the Society as a whole. This happens when it narrows its outlook over the professional horizon or its spheres of influence. But the remotest and least considerable member profits more from the existence of the Society in this respect than the recognized leader or the man of acknowledged eminence.

25 A second function or service of the Society is the offering of the right of association. By this is meant more than the opportunity of social intercourse at meetings to be referred to later, but the privilege of association in the larger sense. It is a great thing for a man to feel that his name appears upon a list which has been signalized by the names of John Ericsson and Chas. H. Haswell, and still bears those of John Fritz, Rear-Admiral Melville, Thomas Edison and Chas. T. Porter, John E. Sweet and George Westinghouse. Such association makes for a sense of distinction and of pride which is in itself a safeguard like the ancient obligation "*Noblesse oblige.*" Can any nobler human ideal be set before a body of men associated together than that it should occur to a man when tempted to lower the standard of professional or business ethics to draw himself up proudly and say "My dear sir, I absolutely decline. There are certain things no member of The American Society does." To do dishonorably is to bring shame and confusion upon all his class and disgrace his associates upon the same roll.

26 Further than this, by reason of this association, the triumph and achievement of one is the glory of all. "This advance in science, in art, in production, in management was made by my colleague and fellow member." This also stimulates the individual to do his own share beyond the confines of his narrower or purely personal interest, inasmuch as he is bound by an *esprit de corps* to confer benefits upon his associates similar to those which he has himself received.

27 And again the member of the Society is privileged by his association to feel that in cities which are strange to him he has yet the right of fellowship with other members there so far as the right may be wisely exercised. The business approach is easier; the road to acquaintance on casual meeting is shorter where both parties recognize the standing of their common membership. All these emphasize however but the more strongly the necessity for safeguarding the quality of the membership, by the proper committee, by the Council and by the voting members, lest abuse of this so great a privilege makes it necessary that the best members should withdraw it.

28 The third function of the Society is that of furnishing the advantages of a body corporate in the profession. These advantages appear both among the common-places of the legal aspect, and also from a general view point. The Society becomes a continuing and permanent body whose policy is unaffected by individual deaths or removals. Hence it may safely be made a custodian and trustee of significant gifts. This very building in which this meeting is convened belongs to the Society and not to individuals. It is the Society who has furnished or is to furnish one third of the ground on which it stands. It is the Society which has furnished the brains and the assiduity whose results appear in the details of its arrangement. If there had been no Society there would have been no building, in whose splendor and distinction each individual is entitled to feel a share. The Society may therefore be made a legatee and beneficiary in wills and testamentary gifts. It can be entrusted with historical material which is so apt to dissipate in the hands of individual inheritors.

29 But in the larger and general sense the Society supplies a corporate unity, in that as an organization things come to it which would not be given to individuals. Nowhere is this more evident than in invitations to visit works or places which would not be opened otherwise, which has happened again and again in the past. The Society as an organization supplies the avenue of approach and contact when a body such as a governmental department desires an action which shall be general, and not that of a few persons. This fact of corporate action calls for emphasis of a principle sometimes difficult to carry

out except with the good-will of all. It is that when the Society is the recipient of special courtesies and invitations which would not be the privilege of all individuals, it calls for withholding of these privileges from those who are not members, but who are present at any time or place as invited guests accompanying members. It will be plain upon a moment's reflection that such persons should refrain from causing embarrassment by their unintended presence.

30 A fourth function of the Society is that of providing meetings of its members at proper intervals during the year. An ideal meeting would be one in which at least three elements were combined in wise proportions. The first is a mental stimulus in the form of live topics of professional interest presented as papers or otherwise; the second is the opportunity for social or intellectual attrition with other minds and temperaments during an association or intercourse lasting long enough for acquaintance to ripen; the third is a mental and physical stimulus and relaxation of tension by a sight-seeing which shall not be interesting only for the empty minded or the uninformed. Danger lies in any excess or undue lack of these several elements. If there are too many papers or too much time is given to their discussion, the meeting becomes a weariness from excess of the mental stress, It was a very good friend and shrewd observer of experience who cautioned the writer in an early day: "An audience has a distinctly marked elastic limit of patience like a piece of steel. Strain that attention beyond its elastic limit, and it takes a permanent set; it will hate you and despise your best works."

31 On the other hand, to have too few papers or on topics of little value and interest, is to make a failure for the earnest and busy man who has a work to do at home and is "straitened until it be accomplished." The Society wants his presence and approving attitude of mind for the good he can do by being there; if he feels it not worth his while to come because the meeting is but a frivolity and undeserving of a serious man's attention, both presence and approval are lost. There must be a serious nucleus, else the meeting is a mere excursion. Too great an intellectual appeal, made at the expense of the opportunity for meeting other engineers for conference, for exchange of experience, for story telling, is to invite the member to stay at home and read the printed papers there at his own hearth. If he loses or must lose the vivifying and rousing effect of the spoken word and the electric snap of meeting mind to mind, why not stay away? Particularly as a man grows older and reaches the plateau of middle life, the advantage to him of the renewal of old acquaintance—to which he clings more and more as his circle narrows—becomes greater and greater. It is a safe-

guard against a stiffening and stagnation. In this view the practice of the Society in registering and even in labeling all members in attendance at a convention is not a whim or a fad. It arises from a definite desire and purpose to make the approach of unacquainted members both safe and sure and short in time required to effect it. We cannot all remember names; to remember faces is for some a considerable effort. The time of a convention is too short to waste any of it in indirect or preliminary effort to know a man. Introduce yourself by emblem and by name, and enrich your memory of the meeting by what the other fellows thought and said. No home reading of the best papers will result in this.

32 The third element or factor in a Society meeting is the sight-seeing. This must be a lure or bait, since the first or intellectual phase is partly attainable at home, and few men are brave enough to confess to the existence of the second factor. But the sight-seeing must have a professional or intellectual content or nucleus, or it will not appeal. It must be the opportunity to see or study new development upon its own ground, or it must give a man a chance to examine a variant upon his own line of work, or by reason of its extent and magnitude or the brains or talent expended on its execution it must at least appear to be worth seeing. Otherwise as before the serious minded and the earnest are not attracted by it. These meetings do not occur in vacation time, they are in the midst of the serious business of the year. A meeting some years ago where the Society went to the sea shore and away from all engineering opportunity, while a memorable one professionally, was yet in the retrospect a terror to use by night against the misdeeds of naughty children. On the other hand, the things the member carries away in his memory are not the papers nor discussions. The pleasures lasting in his recollection attach to the things he saw and noted and the people he met. To repeat the shrewd comment of a gifted member who had been chairman of the local committee, and who was being complimented on the successful visit to a steel works of his city: "The meetings of the Society are like a brick wall. The papers over which the Secretary labors so strenuously are the bricks, but these trips and their opportunities are the cement which makes the bricks a unit." Too few bricks, a poor wall; too little cement or badly chosen leads to equal failure.

33 This discussion of the function of the meetings gives opportunity to record some personal convictions. In a Society which is national in scope and membership, the selection of the places of meeting should have some regard to the center of gravity of the

membership, as it asserts itself territorially. The alternate swing of meetings from the Atlantic slope to the Mississippi Valley has much to commend it; but the extreme is reached or passed when the meeting is so held that both the length of the railway journey and the consequent absence from their posts permit only a wealthy and leisured few to get away to attend it. In other words, the excursion or sight seeing end here overbalances the other features of such a meeting, and many cannot afford it. In this same category is the propositon to hold a meeting for papers and discussion as a feature of an excursion or during its progress. The two elements do not mix; the excursion is spoiled for those who must bear the burden of the session; the session is spoiled because the most desired participants are not there. The only excuse will be when the excursion is so long or so tedious as to be a failure as an excursion—when it ought not to have taken place at all.

34 The speaker has never been a partisan of the formal banquet as a feature of a Society meeting. Unless the Swedish custom prevails of changing seats at the tables, any one meets only those near whom he is seated. Breadth of association or contact is prevented and when fortunate to be among a group of friends, no advances of others are likely; and if among strangers or the uncongenial, few experiences are more dreary. The number of notable dinner speakers among a group of engineers who are earnest devotees of work is small in any case, and most of these are not likely to be present. Dull or futile dinner speech is unendurable. If the dinner is costly enough to be worth while in itself, there is barred out from it a considerable number of men who must regard the expense in planning to attend the convention at all. Shall the ladies present at the meeting be included or not? If included they blank one side of each member so accompanied, and smoking will not be general. Hence, it has always seemed that another form of public social function was much more worth while than the banquet was likely to be; and was very much less trouble to arrange for.

35 The presence of the ladies at the meetings of the Society has been invited and encouraged from the very beginning, not only as a means of pleasure to themselves and those who bring them, but because they had a distinct function in making the meetings successful. The woman in America as elsewhere is the social expert; the busy or lazy man farms out to her the doing of many social duties, in whose absence the community would lapse in manners and culture. Hence her presence and her activities at a meeting tend to raise the tone much above that which would prevail in a purely "stag" reunion.

The man exerts himself in directions of social effort as he would not do in her absence. Her presence also is a restraint, and prevents things from happening which might occur if the man were alone. She secures for the man an access and an ease which without her he would lack. Doubtless also the woman acts to persuade the busy member to bring his participation to the meeting, when lacking her influence the pressure of business would be allowed to keep him at home. His presence and experience cannot contribute to the meeting unless he is there.

36 The meetings of the Society are one of its principal opportunities whereby the Society as such reaches and impresses the general public in the cities where it meets. The professional sessions do not wield a very great influence in this respect; but the other features of the meeting do. Hence it has been felt to be of the first importance that in all its outward relations the professional and scientific sides of its purpose should be strongly emphasized, rather than its contact with commercial problems. To this end, the prohibition of advertising or publicity procedure in its headquarters has always been enforced, and so far as possible also in the hotel corridors and foyer. If the commerial instinct for business were once allowed a foothold, the meetings would become the arena of industrial and commercial rivalry, and their high character would disappear. At the meetings also, where the membership comes together on the social plane, the Society is rather comparable to a club, than to a purely impersonal professional body. It offers therefore the club opportunity for discussing business or personal interests and ambitions concerning purchase and sale, which are entirely legitimate if not abused. If the members do not desire immunity from interested partisans of any specialty, the Society can not secure it for them. It may discourage only the making of it inevitable.

37 The view of the Society as a club during its meetings justifies it in exercising the right to protect itself from an undesirable member who would there bring it into disrepute by habits or behavior in which the majority cannot uphold or defend him. It may not be the primary business of a Membership Committee entrusted with the consideration of a man's professional fitness for membership to reject him if he is so addicted to the use of intoxicants or other drugs as to be likely to bring discredit on the Society at a meeting; the membership however will surely defend such a Committee when it seeks to protect the fair fame of the body as a whole. This must be the explanation of the policy of not admitting to membership candidates who belong to a race with which the Caucasian does not socially assimilate.

The man may be all right professionally but his admission would be contrary to good policy. The Society has also the same right to protect itself against any who are known to be prone to unprofessional conduct of any kind. It must do so if the function and privilege of association earlier discussed is to have any meaning.

38 This division of the subject would not be complete without a treatment of the question of local meetings of sections of the Society. Such sections may be either territorially grouped, or by topics and common interests. As provided for in the By-Laws and Rules of this Society they are to consist of elected members only as regular members of the Section, non members having only the guests' privilege of participation in papers and discussions. Members of sections therefore derive their advantage from the existence of the national body and from association with its members independent of the local section, and the advantages of the publications, hereafter to be referred to, from the same fact as well as the general meeting privileges. What they derive in addition is the privilege of meeting other members at shorter intervals, and without entailing expense for a journey or a difficult absence from home. But the very frequency of the meeting and the ease and absence of sacrifice by which it is secured make for a lessened interest in such meetings after the first novelty has worn off and the acquaintances have been formed. The novelty of the more infrequent general meeting is lacking, every one becomes tired of hearing the old "stand by's" at every meeting; the supply of local material for discussion dries up, and what comes from the office of the national body does not happen to stimulate. Then the section becomes a social body only, and does not help the national body particularly, if it does it no harm. It would be much more useful if what is sought by the section or local chapter were sought in another way, or by means of a body made up of both members and nonmembers, acting in some affiliated relation with the national body, whose discussion properly therefore falls into the final part of this paper.

39 In the fifth place, so long as the Members, Council and Membership Committee are sensitive to the duty respecting the quality of the applicants for membership, it will follow that the fact of membership in the Society is a stamp of quality of engineering achievement—a seal or *cachet* of reliability and professional standing. Three or five men proposed this man, and answered most searching questions as to his performance and eligibility. A Membership Committee of five experienced scrutineers canvassed the application and the replies of the backers, and perhaps went outside to establish the candidate's

claims or to force the proposers to effective defense of them. Then the Council criticized the report of the Committee and ordered the man's name to ballot; and finally among all who voted on his name there were not found two per cent who knew anything against him which would justify his rejection. All human judgment is fallible, of course; but the successful passage of such an ordeal is a strong favorable presumption as respects any man, to say the least.

40 Now this stamp of approval upon every enrolled member is a very precious possession. The key to admit to it is held by the voting membership, and those who propose candidates. The Membership Committee unlock as it were an outer door to the vault, but they do no more than this. They do not admit to its privileges. Hence the reciprocal duty of the members is made very plain; if the Society has a function or service along this line, the individual voter is obliged to the greater scrupulousness in the exercise of his duty. If anybody can get into The American Society then membership in it will be little prized. If this separation of the members of the profession into the class within the Society and the class without it be objected to as anti-social, aristocratic and undemocratic, the reply would be that so also is the family. Any man can get into the Society who has shown himself to be qualified to do so. His objection must be against his lack of qualification and not against the Society which upholds a standard.

41 The sixth function of the Society is its creation and maintenance of a Library. It was not so long ago that every professional man had his private library of some extent, containing the books and periodicals he specially valued and used. But in recent times the enormous increase in the number of books required for any library with a pretense to completeness; the necessity for rapid expansion if it was to keep pace with the progress of the day, the investment required in society memberships to secure their publications, and the bulk of the current periodical literature of the profession have all combined to bring about a change. The housing and the care of a worthy private library became a problem practically insoluble for the individual, either in office or in home. Hence the opportunity arose for the Society Library, doing for all the members what each could do for himself only with the greatest difficulty or prohibitive expense. To reduce the unnecessary duplication of books and transactions and periodicals required only for occasional reference is a measure of evident economy and advantage..

42 A reference library which is not also a circulating library can only be made really serviceable to members who live near enough to the

library shelves to enable book and reader to be brought together at the home of the book. · It is one of the problems of the immediate future to develop the circulating function of duplicate books and publications in a practical way, which shall protect the interests of all parties, enabling the library to render the largest net service. It would seem both narrow and unwise to lock up the library from the reach and use of those not fully qualified for membership, or not able to become such for other reasons. The Society therefore permits and invites a public use of its collections in addition to the proprietary use by the members. If such public use transcends the private use, then to impoverish the shelves by circulation without duplicates seems too heavy a price to pay. It should be noted that the coming together of the libraries of the three societies named as Founders of the Engineering Building has not only more than trebled the scope and extent of the library for all users, but has opened up the circulating possibility by bringing an increased volume of duplicates together.

43 The library also offers the possibility through its staff, of having researches made for members at a distance, and extracts made and sent, which could not be done in a public library, but which is normal and appropriate in one belonging to the member as of society right. The library can also be made custodian and legatee for books of value and usefulness when their former owner has no longer occasion or convenience to control them himself and give them room and care.

44 The foregoing services rendered by the Society to its members are all in an imponderable class, and do not have a value which is appraisable in legal tender. The non-member cannot buy them, however wealthy he may be. This makes them therefore of all the functions of the Society the six which are the most to be prized. They are like a franchise, in that the benefits which flow from them are not common to all members of the community but are conferred by special act of the corporate body. There comes next a function and benefit which is extended to members of the Society, but which differs from its predecessors in that it has also a material or appraisable cash value and that it may be secured also by non-members for a price. It is the privilege of the publications of the Society. It must not be inferred from the fact that this return to the members is put seventh upon the list that it is therefore an inconsiderable or secondary feature. It is on the contrary one of the most significant and important, and one around which are grouped many of the activities and much of the organization of the Society's business office. It is the item for which directly and intentionally it makes its largest expenditure; it is the element which conditions very largely the esteem in which the Society

will be held by members within and observers without. On the other hand, the putting of six other elements of Society worth and function before it, is intended as an attack upon an erroneous opinion held by some who have never had it attacked, that the publications of the Society are the only or the principal return to them for their dues and continued membership. When the volume or value to them of the Society's annual output of papers and discussions fall off in their opinion in any year, this is an adequate reason for discontinuing their membership. The existence and value of the preceding factors first enumerated should be sufficient rejoinder in themselves.

45 The publications of the Society come to the membership in three forms. The first is the monthly magazine or bulletin which is designated Proceedings, and distributes papers to be read at a future meeting, discussions on papers current or past, memorial monographs, book-lists and Society notices and circular literature. These replace the "Advance Papers" of the former day, and so far as possible incorporate the individual and separate circulars which used to be issued. Some of the matter in this magazine is not to be of permanent record, but of present and current interest. The second form is the bound volume of papers and appended discussions with index and consecutive paging, intended to be the permanent record for future reference. This must issue of course after the regular meetings and at an interval sufficient for the execution of all editorial work required. It need not contain all that the Proceedings did by reason of the limitations of bulk and the inexpediency of permanently preserving everything that every one said in all discussions. But this book, known as Transactions is the monument of the year's professional work. The third form is the pamphlets "Reprints" from the volume of Transactions, being the excerpts therefrom which contain an individual paper and its discussion, printed from the same type as used in the volume. These are of use when single copies of one paper are desired for any purpose, and a stock of them is kept on hand to meet calls from the future.

46 The publications at present include only material originating in the membership for presentation at meetings, and the result of the activities of the Meetings Committee in persuading contributions from members and others upon topics which they suggest. It has been felt for some time that these were unnecessary and undesirable limitations to place upon the possibilities of usefulness of the publications. They would be of incalculably greater value and use if they could be made to include abstracts of papers before other professional societies than our own; reviews of contributions to technical journalism,

book reviews and contributed material by non-members on current achievements, new work, and live topics. An index of professional literature in society proceedings and other journals would be of the greatest value. In fact there does not seem to be any reason outside of the cost of making it so, why the publications of the Society should not be placed upon such a plane of value and usefulness that no engineer within or without the Society could afford not to regard them as a cherished possession and a valuable asset. Here however, also, as in the case of the value of *cachet* of membership, it is the willingness of the member to give of his time and service to the writing of papers and to the contributing to the material for the publication work of the Society which must be the great factor of success.

47 The eighth and final function of the Society is that which it contributes through the personnel and organization of the official staff of such a body. The Secretary is the natural and proper head of the Society office with such help in the editorial, the correspondence, the accounting and the clerical detail of the work as the size of the Society and the volume of its daily business make necessary. The conduct of the Society is a business and of no inconsiderable magnitude. The office is also most directly concerned in carrying on the detail directed by the working standing committees and under the Council. The degree and quality of the organization of the Secretary's office for its functions is the measure of its usefulness and service. The American Society of Mechanical Engineers may well feel proud that by the unselfish and self sacrificing devotion of a special committee in which a past president of the Society, an expert in such matters, was the leading spirit, the organization of its office is as nearly a model of such an undertaking as brains and good will can make it.

48 Such an office discharges functions to the membership at large and as a whole, and also to individuals. Perhaps the most important duty of the first class is the preparation of the semi-annual lists of members and its issue. This is not only a professional directory of the highest order, enabling members to know in what specialization every other is engaged; but it is a channel for intercommunication whereby any member may feel sure of reaching directly the other members if he so desires. Its correctness and its completeness are therefore the factors of its value. This explains the trouble taken twice a year to ask the members about their address and their professional engagement. The Secretary's office also reaches every member for service in the matter of the candidates for membership, the voting functions of the members and the details of the meetings as they are to occur.

49 Besides these public or universal functions rendered to all

enrolled members, the Society office may be compared to a ganglionic center through which the mentality of its management becomes converted into activity. Without the organization there would be no organ through which the Board of Directors or Council of the Society could exercise their functions as Trustees. The existence of elective office in the Society is made necessary by existence of administrative functions to be exercised. If there were no business there need be no President nor Vice-President, nor Managers to constitute the Council, nor need of choosing such from among those whom the profession is glad to honor. If a distinction attaches to membership in the Society among the ranks as a private, how much more impressive the *cachet* given to the chosen officers. It is safe to say that office will never reach any save those who are without a blemish; to be entrusted with it an honor to be coveted, to be worn modestly, to be safeguarded jealously from harm or injury by error or misdeed on the part of its wearer.

50 The office staff renders also individual service as a medium of exchange of knowledge of men and of opportunity. Lines of communication and of acquaintance radiate from it as a center to the remotest bounds of the membership. Along these lines may flow question and answer, problem and information, need and its supply. Much of the Secretary's correspondence is of this class, which does not fall into the channels of routine business and automatic office machinery. The office is also the channel through which from without the stores of influence and capacity within the membership may be reached for the rendering of civic or national service either by the Society as a whole or its individual members in particular, on commissions on committees and in other important ways. In addition to these of course are the unclassifiable services which are personal and individual.

51 Is the privilege of service and of function all on one side, or has the Society the right to ask from its members a reciprocal duty to itself? The latter, no doubt. It is the duty of the individual member and his privilege to make at least the following effort:

a That no fancied advancement of his personal interests by a member should lead to any act or practice which will stain his character and injure his fair fame. If membership and its asssociation carries distinction when its members are distinguished, so the same force carries disgrace to all with the disgrace of the individual. It is for this reason that the Society for its own protection must have a means of ridding itself of a source of defilement through the unprofessional behavior of any.

b The individual member should seek to build up the Society in professional and numerical strength. The quality must be kept up for the sake of the elements advanced early in the argument, but influence goes with numbers of the right sort, and opportunity for wider service follows with the increased income on the one hand, and from increased scope of interests on the other. The Society has barely begun to draw from the great reservoirs of professional activity throughout the busy industrial centers of the United States; the world is ours also.

c The individual member should build up the activities of the Society as respects its papers and discussions. This calls both for personal effort in contributing himself from his own experience and work, and for the interesting of his neighbor also to do the same thing. If the dream of making our published Proceedings and Transactions a professional necessity to every engineer is ever to be fully realized, it must be when from all over the flow of knowledge, data, skill and experience into the Society's channels is deep, full and never failing. What it will mean to the Society if these ideals are made realities, it is beyond the clearest and most hopeful vision to pierce and prophesy.

52 Consideration must now pass to the final topic under review, which is the possible function of the Society to the profession who are not enrolled in its membership. If the foregoing argument has been conclusive, it is plain that such service or functions should be discharged without a prejudice to the interests of the membership itself. There are two extremes of view and opinion. The one is the aristocratic idea, that the Society exists exclusively for the advantage of the members. This in a modified form may be called the English idea, and is natural where passage from class to class is not easy by reason of their quite definite stratification. This plan would have the privilege of membership narrowly restricted, open only to proved and distinguished ability, and therefore to somewhat advanced years in the majority of cases. The other extreme is the communistic view professionally, that all adherents or practitioners of engineering are equally eligible, regardless of professional achievement or training. All draw equally from the common fund of professional advantage from membership; but of course there are no private fortunes of distinguished advantage, and no one draws as much in the larger community from an equal fund as he does in the former case. This again in a modified

form from the extreme may be called the German idea. The American does not fancy either extreme: but between them is room for a large diversity in the middle space. It was proposed in this Society (1890–1900) to create such an aristocracy. It has been urged (1902–1904) to so multiply the feature of sections of the Society as to approach to the more communistic or continental idea. The safe course is between these extremes. In the British aristocratic atmosphere, membership in the Institution carries with it a distinction which is recognizable: the advantages of membership in the German Verein of Engineers are on quite a different plane. Is a policy or plan possible which shall secure the advantages of both? The writer believes it is.

53 A membership which is ill-assorted and non-homogeneous will not be a strong one regarded as a unit. The differences in education, in extent and quality of experience in culture and social equality as the former factors affect this, would seriously interfere with the success and unity of the meetings. Unwieldy size of meetings restricts the number of cities available for such meetings, and shuts out many places altogether for lack of hotel and housing accommodations. To extend therefore the privileges of the first five functions of association due to its existence, to the inferring of distinction, of meetings and of corporate unity either cannot be brought about at all to those not eligible under the present wise standards, or else would become theirs at a price so great by reason of the debasement of the coinage in which their value is reckoned that it ought to be paid. No such restriction holds however with respect to local meetings which may include members, to the library, to the publications and to the office organization of the Society.

54 The extending of the library function has already been referred to, when it was made a free public reference library. It is now open to free consultation by non-members as well as by members, the only present difference being that members are permitted access to shelves and alcoves directly, while others must work through the librarian and his staff in a general reading room. As the library grows in usefulness and in the members who use it, it will doubtless happen that the system of management will have to become identical for both groups, and the non-members' privileges be the same as those of the member. The same conditions—mainly financial—which will permit the addition of the circulating feature of the books among members, will also permit a similar although perhaps a more restricted circulation among the engineering public who are not members. This usefulness therefore would seem to be provided for.

55 The usefulness of the office organization under its present completeness and elasticity would seem to be limitable only by the demand, made upon it, the room for its accommodation, and the cost of its compensation. If extensions of its functions are accompanied with a proportionate return in income, the possibilities of this function would seem to be provided for as widely as use can be found for it.

56 The publications of the Society are available to non-members by subscription and by purchase. The cost of composition, illustration and editorial revision is incurred for the first copy of any paper, and all contracts and systematization are provided for the first paper secured and issued. After that it is merely the paper, press-work and distribution expenses which have to be met, which are the least in amount and vary directly or in a diminishing ratio with the number of copies made. Hence all that is necessary here is to create the demand by making the Proceedings and Transactions so valuable and so comprehensive that no member of the profession, member or non-member, can afford to be without them on his desk or in his reference library; and the result is won. This also would seem a result and a function for which all preliminary steps had already been taken. What remains is to do it.

57 This leads up to the final functions of the Society, with the urging of which this paper will have accomplished its ultimate purpose. It is that the Society should foster and cause the growth of other organizations or societies or clubs, specialized either by their location in city or district or state, or by their particular line of study and pursuits. Such bodies should be entirely autonomous as respects their officers and procedure and rules and financial support. Their membership should include both members of this Society and other engineers, the latter embracing both those who are eligible to membership in this Society, but having a prior allegiance to some other Society or do not as yet want to join any such organization, and those who by training or experience are not yet eligible to any existing national society. Such bodies should be known as: "The ——— Society of Engineers," or some equivalent name, the blank being filled by the name of the place where they prefer to meet, and the full designation to be "The — — Society of Engineers Affiliated with The American Society of Mechanical Engineers." The emphasis is to lie upon the fact and relation implied under the word "Affiliated." The members of the local or specialized body would not be members of The American Society and would not or should not call themselves so. They are members of their own society. Their autonomy and self support secures for them the dignity and responsibility attaching to their

for its success or failure by reason of the effort put forth by those interested.

f The local by operating its business detail through the office of the national society obtains the pecuniary advantage of the larger scale of business in The American Society and the service and coöperation of its trained experts. Their accounting and purchases, as well as their printing, could be done for them at much better advantage in the large office. If accounting and addressing of envelopes and circulars were done at The American Society office, the office expense of the local would disappear, and the cost of the former could be taken care of in its appropriation to the latter.

61 Of course the financial responsibility of The American Society would have to be safeguarded by limiting the appropriations for the locals both in period and in amount, and making them conditioned upon a return from the local satisfactory both in quantity and quality.

62 The word "local" has been used in the foregoing as descriptive of the affiliated body, inasmuch as usually such a Society will be made up of those residing in or near a city or town. There is nothing in the plan however to preclude an organization already existing and made up of specialists in any line, from asking affiliation with The American Society under its provisions. The body may now be national, and having for its special topic of discussion the engineering of the motor vehicle, or that of the production of artificial cold, or certain sanitary problems with a mechanical outlook. They would benefit by such affiliation and they would at the same time strengthen The American Society of Mechanical Engineers, and sacrifice nothing themselves.

63 The writer therefore as he lays down his official insignia of service after these many years, leaves the foregoing suggestions for the elaboration of his successors. All the organic change which would be necessary would be the creation of a Standing Committee on Affiliated Societies with the required By Laws for its guidance, on the same footing as the Research Meetings, Publication and Library Committee, now in existence. The rest the Council may provide for by resolutions and standards in the Secretary's office.

64 If these ideals and possibilities shall prove to be practicable and realized, the opening of the new Engineering Building and the twentieth century will mark the beginning of an era of progress of prosperity, of splendid usefulness and brilliant achievement which will give to the Society position and recognition which has never been dreamed of before.

No. 1165

THE RATIONAL UTILIZATION OF LOW GRADE FUELS

WITH SPECIAL CONSIDERATION OF THE APPLICATION OF GAS PRODUCERS

BY F. E. JUNGE, BERLIN, GERMANY
Member Verein deutscher Ingenieure

GEOLOGICAL RETROSPECTION

It has been estimated by Liebig that the quantity of dry organic matter which is produced by one hectar of farm land, or meadow, or forest, in middle Europe, is approximately the same, namely, 2.5 tons per annum. The output varies according to climatic conditions and geographical location, being larger in the tropics and smaller in the arctics and in the desert regions. Of these organic substances, which consist chiefly of cellulose ($C_6H_{10}O_5$), 40 per cent is carbon, so that, theoretically, the total annual coal production from vegetable materials amounts to 13 000 million tons, which is not quite fifteen times the quantity of coal actually consumed in the world's industries.

2 The assimilation of vegetable matter, or the formation of hydrocarbons, is accompanied by an absorption of carbon dioxide CO_2, from the air, while oxygen O_2, is liberated. If all plants were to accumulate their solar energy in the form of coal our atmosphere would soon be deprived of its CO_2 contents, since about one-fiftieth of the total amount is thus required. So nature has provided that only a fraction of one per cent of the theoretical coal formation is actually reserved in the form of peat, lignite, bituminous coal, anthracite, oil and natural gas for the benefit of mankind. The rest emanates through natural deterioration in the form of gas and reënters the cosmic cycle as carbon dioxide.

3 In contrast to this continuous process of slow combustion stands the exploiting of the world's fuel materials for men's domestic

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and public utilities and comforts. The kinetic energy of coal which the quiet evolution of centuries has gradually stored up in the sedimentary layers of the earth's crust, is squandered lavishly day by day at an increasing rate of consumption, and hardly 5 per cent of its total calorific value is regained as heat, or light, or power. One thousand million tons of coal, and more, which are thus used in the world's industrial pursuits per annum, return to the atmosphere 1/600th part of their CO_2 contents in the form of exhaust products, and exercise an influence on the temperature conditions of the earth far greater than is usually suspected.

4 The same oxygen that was formed as a by-product of the assimilation of plants millenniums ago is now extracted from the atmosphere in order to support combustion of the carbonized products in boilers, furnaces and gas generators. Its total quantity corresponds approximately to the weight of fossil coal which is accumulated in the sedimentary strata. Atmospheric nitrogen, N, the third element of importance, owing to its chemical inertia, has very likely remained unchanged in the course of time.

ECONOMIC ASPECTS

5 The question whether an exhaustion of what we have termed our irreplaceable fuel resources is a danger for the life and prosperity of future generations, can only be discussed on the basis of theoretical prognostications and speculative arguments. The other question, whether for the benefit of present activities it is wise to economize in the methods of utilization of these resources, cannot be answered but in the affirmative.

6 That individual, or company, or nation will be superior, commercially, to others which can get the most efficient service from the cheapest reliable source of labor, whether manual or mechanical. Never is superior talent engaged for low class work, if there is an alternative available to get adequate help at low prices. Likewise it is but a matter of political prudence for a nation to exploit the low grade fuel materials of the country, such as peat, dust coals and refuse, if they can be used for the generation of heat, light and power, instead of wasting anthracite and coke, and to reserve the latter coals for more profitable and important uses in the metallurgical and other industries. An efficient utilization of coal, generally speaking, tends toward the preservation of national values, making a country self supporting and independent on the world's markets. It also aids

the prevention of hygienic abuses which, if not amended, are apt prematurely to weaken the earning capacity and the industrial activity of a nation.

7 The conservation of the higher grades and the utilization of the inferior classes of coal has still another aspect to it, namely, that of industrial expansion over territories which were hitherto undeveloped and of no direct value to their owners. All industries depend for their existence on the availability of some form of energy. Nor is water power, which with proper utilization can now be had almost everywhere in the world, always the agent best suited for certain purposes. Thus iron and steel works depend on the continuous supply of high grade fuels such as anthracite, coke and charcoal for the stability of their production. Where these are not available the richest ore reserves are practically worthless. Either the fuel must be transported to the ore or the ore to the fuel.

8 But transportation itself, whether using steam or electricity or gas as motive power, depends largely on the availability of coal to support it, and the cheaper the fuel can be supplied the better for the railroads, for the industries and for all concerned. In those cases, and there are not few, where conditions of service have grown beyond the capacity of steam locomotives, and where electrification of trunk lines connecting great centers of population and industry is becoming an economic necessity, there the large interest on the initial capital outlay for the new equipment must be offset by a saving in fuel cost, which is by far the largest single item of operating expense.

9 So from whatever point of view we look at the problem, it remains a matter of the greatest economic importance to find methods and means for utilizing the enormous stretches of lignite and peat lands, especially those located in the neighborhood of large undeveloped bodies of rich ore which abound in remote districts of the United States and elsewhere, and, either to transform the raw coals into some form of available energy which can be transmitted over long distances at reasonable cost, or to refine the low grade fuels into superior products such as brickets, or coke, or chemicals, that they may serve as a basis for other industries to grow upon and to prosper. The question which remains to be settled then is not *whether* we should use the inferior classes of coal, but *how* we can use them most efficiently.

10 The effect in a country like the United States of an enormous wealth of natural resources and of an extensive inland market which is protected against foreign competition by high tariff rates is, naturally, to advance the formation of great trust-like combines, to promote large scale production and to favor the standardization of man-

ufacturing methods, which in turn bring large remunerative returns to a few favored individuals, resulting in a rapid accumulation of capital such as is, admittedly, unparalleled in the world.[1] But, at the same time, an ample supply and an ease of disposal of raw materials and finished goods are apt somewhat to diminish the individual and coöperative endeavor of industrial circles toward the attainment of economic excellence in the utilization of inferior products and of such as promise no immediate large returns on the capital invested for their exploitation. On the other hand, scarcity of supply and the necessity to face competition and the urgency to conquer markets at home and abroad, will justify and promote every legitimate effort on the part of manufacturers and consumers, aided by a judicious administration, to procure the best service from the lowest grade of sufficiency.

11 It is evident, therefore, in some smaller European countries, for instance in Germany, where we are supporting over sixty million active people on a territory four-fifths the size of Texas, and where the available fuel resources, especially the high grade ones, are quite inadequate to meet the demand, that the art of utilizing inferior classes of coal, or oil, or refuse must have been cultivated to a higher degree than anywhere else. Thus the very poverty of a country becomes ultimately a source of income to its inhabitants by stimulating the manufacture and the sale of highly efficient apparatus, machinery and processes, and even of skilled talent, to foreign people and markets.

12 Hence it seems reasonable to conclude further—with due consideration in the different countries of the geographical, economical and governmental differences and of the differing industrial policies —that the evolution of that branch of industry with which we are here concerned will take, in the large and scarcely populated countries, a course similar to the development it has taken in those that have to support the largest number of people per square mile of area.

13 With these and other considerations in mind it would seem a very wise policy of President Roosevelt's administration to aim toward preventing the passing of the coal lands of the United States into private ownership and the control of corporations.[2] Of the

[1] It is interesting to observe that 25 per cent of the business wealth of America is now under corporate control, and that seven eighths of the country's wealth, seven hundred billions, is owned by less than one per cent of the population.

[2] It is estimated that already about one-half the total area of high grade coal lands in the West is under private control. Only 30 000 000 acres are left for the Administration to take action upon.

advantages claimed for the proposed leasing system there are three that bear closely on the subject with which this paper is purported to deal: (1) Government control will prevent waste in the extraction and handling of fuels. (2) It will permit the Government to reserve from general use fuels especially suitable for metallurgical and other special industries. (3) It will enable the Government to protect the public against unreasonable and discriminating charges for fuel supplies."

TECHNICAL CONSIDERATIONS[1]

14 Turning to the technical aspects of the problem, it is opportune first to get a clear idea of the meaning or the signification of the term low grade coal. What does it imply? There is no standard of designation to refer to and none to establish. We cannot graduate the place allotted to each fuel by its relative heat value, nor can we fix its rank in the scale according to the measure of volatiles contained. The transvaluation of by-product values—to adopt an expression of Kant's—that is, the constant change in the appraising of, or in the amount of returns realized from the sale of chemical and other by products which are gained from the various coals, and the constant improvements made in the refining and briquetting of raw materials, make it impossible to define clearly the limits below which a coal becomes inferior.

15 If, owing to their low carbon, high moisture and high ash contents, we speak of lignites and peats as of low grade coals, we are following traditional customs rather than plain facts based on recent developments. Likewise there are conditions under which the smaller screenings or sizes of a high class lean coal may rank equal or lower in monetary value—for instance coke-dust and anthracite-dust which sell at about one-tenth of the price that corresponds to their heat value—than the fuels quoted above. It is only refuse such as culm banks and other waste, which are obtained in very large quantities in coal mining pursuits and which hitherto escaped utilization entirely owing to their excessive ash contents (up to 65 per cent), that we can rightly speak of as low grade coals, since both their contents of fixed carbon *and* of volatile hydro-carbons is small.

EFFECT OF ASH, MOISTURE AND VOLATILES

16 Generally speaking, ash and moisture in coal have the disadvantage that they displace valuable combustible matter, thereby

[1] For detailed information refer to the author's works on "Gas Power," Hill Publishing Company, New York.

reducing the heat density of the fuel, that is, its thermal value per unit volume or space occupied. This inert material must be paid for by the consumer, hence the cost of digging, transporting and handling it must be charged against the coal, thus making it inferior as a fuel to others that possess a higher content of combustibles. Ash and moisture introduce another disadvantage in that both absorb heat. This heat is used for evaporating the water and for bringing the non-combustible matter to the temperature of the fire and maintaining it at that point, so that less heat remains available for useful purposes.

17 In boiler work ash acts not only as a diluent, reducing the heating power of the coal on the grate, but as an actual obstruction to the combustion process, the effect of its presence being thus doubly harmful. When analysing some characteristics of coal as affecting the performance with steam boilers, W. L. Abbot found that when the ash contents of the coal (screenings of various size) had been increased to 40 per cent the coal could still be burnt and would heat the water up to the boiling point, but it would not produce enough heat to make steam. So when heating boilers the useful effect from the fuel drops to zero with 40 per cent of ash, notwithstanding the fact that the other 60 per cent of the composition is pure coal. It is remarkable that, although over half of the composition fed to the fire is fuel, it burns without producing any useful effects.

18 In producer work these drawbacks are not only less felt than with grate firing, but they are actually turned to advantage. Bulk of apparatus and heat radiating surface are factors of secondary importance with producers. They only serve as the central means for making a suitable gas which is used subsequent to its generation and outside of the producer for heating, lighting or power purposes in regulable quantities according to the momentary demand. Heat that may radiate through producer walls or pipings can be used in a convenient manner for preheating either the combustion air or the coal or the water or what other constituents may participate in the gasification process.

19 High ash contents, though increasing the dust contents of the gas and producing clinkers and slag when unduly heated, will promote an even flow of the material through the apparatus when properly treated. Of course, it is preferable to reduce the contents of incombustibles in a coal by washing or briquetting, if there is an alternative to their use as raw fuels at the spot, since this will lessen the amount of handling and poking required. Also, it is obvious that the higher the quantity and the quality of combustibles in a coal

and the more uniform its size, the greater will be the capacity and the efficiency of the producer plant, and the more uniform the composition of the gas rendered.

20 But where it is necessary or desired, for reasons of economy, instead of refining and selling the coal, to use it in its original raw shape at the mines at the lowest possible cost and with highest efficiency, then excessive ash contents cannot be regarded as a limiting condition, when producers are employed. In Germany we have been gasifying mine culm, a material containing hardly 25 per cent of combustible matter and up to 65 per cent of ash, in Jahns producers for the last four years with entire success.

21 Moisture, up to a certain percentage which varies with the type of producer used, is not detrimental either. Water, regardless of whether it is supplied with the coal, or with the air, or in the form of steam, acts in one way similarly as the water does in the cooling jacket of a gas engine, namely, as a preventative to excessive temperatures, thereby enabling the working process to be performed without interruption. Excessive temperatures, besides promoting the fusing of the earthy constituents of the charge to slag, are harmful to the materials of the producer wall and grate. With proper adjustment of the steam supply, where steam is added, it is possible to prevent the formation of big lumps of clinker with almost all grades of coal.

22 Water vapor, besides increasing the efficiency of the producer by reducing temperatures all around, when drawn through the incandescent zone or otherwise sufficiently heated, will even serve as a fuel element, enriching the gas by an addition of hydrogen and oxygen. Hydrogen, within certain limitations, is a desirable constituent because it increases greatly the calorific value of the gas and promotes flame propagation. Oxygen will combine with carbon to carbon monoxide and is desirable because it replaces a certain weight of air with its accompanying nitrogen. Nitrogen is an inert diluent, chemically speaking, being of little use to the gas. In the gasification process however nitrogen plays no unimportant part since it acts as an equalising and transmitting medium, absorbing heat in the lower incandescent zone and yielding it again to the upper layers of coal on its way to the discharge duct. It can be taken, approximately, that two-thirds of the total physical heat are thus conveyed by the nitrogen through the apparatus in up draft producers.

23 The fact that the moisture in coal absorbs part of the heat of gasification is an advantage in producer work, while it is a drawback in grate firing. Moisture is harmful only when large quantities of it are contained in the gas as produced. This water vapor must be

removed from the gas either by dry scrubbing or cooling or compressing, else it will reduce the heat density of the gas and, when the coal contains sulphur, it will produce a corrosive action in washers and pipes, besides having a destructive influence on furnaces and in the steel making process.

24 When dry coal is gasified we obtain temperatures in the gas between 600 and 800 degrees centigrade. When the coal is wet, or when water is added we get temperatures of from 400 to 500 degrees. Hence there is a smaller loss through external cooling of the gas and radiation in the piping. It should be remembered that only a small portion of the total heat that is lost by radiation can be used for regenerative purposes in the producer. Also that it is desirable for all purposes, except when producer and furnace form one unit, to have the gas leave the producer as cool as possible.

25 If we can control the amount of moisture participating in the gasification process, for instance by regulating the admission of steam to a comparatively dry coal, there is an economic maximum for each material which we must not surpass. In one particular case in England it was found that the use of steam over and above that required to saturate the blast at 60 degrees would not lead to higher thermal efficiencies. This will hold true for one kind of fuel only. When using raw fuels of the lignite and peat class we have to contend with a certain percentage of moisture which cannot be expelled from the air-dried coal except at high temperatures or by briquetting. Therefore so much water must partake in the gasification process, and the question arises: what are its effects, and how can we utilize it most advantageously?

26 The fact is that fuels with some moisture contents and fat coals, which absorb part of the heat of the gas in the distilling zone for driving off the volatile compounds and for splitting them up into stable constituents, are actually superior to lean coals like anthracite and coke as regards efficiency of utilization in gas producers. They also possess this advantage that the gas made contains luminous substances which greatly facilitate the adjustment of gas fired furnaces. Fat coals are only inferior to lean ones in that they are apt to change their volume and shape in the producer while being heated, therefore requiring more frequent poking. Also when exposed to the atmosphere they will, during storage, lose about 1.7 per cent of their gas contents in one week, thereby reducing the output of gas and by-products, if the latter are recovered.

27 Attention is called to the interesting experiments of Dr. Wendt made in Germany in which he determined the relative efficiencies of

producers working with and without an addition of water. Ordinary boiler coal of high volatile contents was used. When gasifying coals containing much pure carbon a greater difference in efficiency was noted between the dry and the wet process than with others, also a greater difference in the sensible heat of the gas which may be lost through radiation and cooling.

28 With dry gasification of pure carbon there is, theoretically, 70 per cent of the heat value of coal contained in the gas as produced, with wet gasification 85 per cent. In the first case the sensible heat of the gas when leaving the producer is 29 per cent, and in the second case 9 per cent of its calorific value. In practice the heat value of dry producer gas ranges between 900 and 1100 calories (100 and 123 B.t.u. per cu. ft.); that of wet producer gas between 1100 and 1400 calories (123 and 157 B.t.u. per cu. ft.). Higher values are the result of momentary, not of normal conditions in the producer.

29 As for the principal constituents of the gas the analysis shows, approximately, 32 per cent CO for the dry process and 25 per cent for the wet one. The contents of hydrogen is 8 per cent and 14 per cent, and that of nitrogen 60 per cent and 50 per cent respectively. Carbon dioxide ranges up to 3 and 4 per cent, Methan from 1 to 3 per cent. Besides there are traces of acetylen, oxygen, etc. So moisture in producer fuels acts practically as a transformer and distributer of heat, reducing the sensible heat of the gas but increasing its calorific value and heat density, thus making it better fit for outside distribution.

30 While for gas engine work there is a rigid limit to the hydrogen contents of producer gas, drawn by premature ignition troubles, there is little accurate knowledge available on the question whether high hydrogen contents is harmful when the gas is used for heating regenerative furnaces. Some contend that at temperatures beyond 1500 degrees centigrade dissociation plays no unimportant part and that the quick destruction of furnaces is the result of high hydrogen contents in the gas. Others maintain that it is the water vapor accompanying the hydrogen which is responsible for the damage wrought, and that a high content of CO is more desirable when a soft reducing flame is required in the furnace.

31 With thorough utilization of the radiating heat of the gas for regenerative purposes up to 90 per cent of the heat value of the coal can be regained in the form of producer gas. But there is a limit to preheating, the same essentially as that drawn to dry gasification, namely, the attainment in the producer of excessive temperatures which its structure and material cannot withstand. When the

[illegible]

34. Automatic charging [illegible] that it increases greatly [illegible] gas, there is this misapprehension prevailing among men not familiar with producer practice, that these devices have the same general effect as automatic feeding has in boiler work. They are supposed to eliminate the employment of manual labor, thereby reducing the cost of the operation of the plant to a minimum. This is only so with coals that do not require treatment subsequent to their feeding to the producer. With the bad caking variety, which abounds in this country, the constant poking required represents a much greater amount of manual work than the charging process proper. So in this case, except

perhaps in very large plants, there is no saving realised through automatic charging unless mechanical poking is adopted at the same time. The question is again strictly one of locality, size of plant and kind of fuel used.

35 Though, as we have seen, there are limitations to the efficiency of the conversion of the kinetic coal energy into gas, yet the gasification of coal in producers is superior in almost every respect to grate firing. One reason which has not been mentioned is that in producers complete and smokeless combustion can be attained with a surplus of 20 or 30 per cent of air beyond the amount that is theoretically required, while with grate firing a surplus of air of from 100 to 250 per cent over the theoretical maximum must be expended in order to attain the same result. Hence by far the largest portion of the heat that is generated on the grate is lost on account of the high temperatures at which the products of combustion leave the flues. Therefore, the larger the quantity of products of combustion per unit fuel the less efficient will be the utilization of the combustible material when grate firing is employed, while with producers this deficiency can be more nearly compensated.

36 Enough has been said to establish that high ash and moisture contents in a coal do not preclude its utilization in gas producers, and that the utility of these apparatus ranges far beyond the realm of application of grate, furnace and boiler. Of course, if we come to raw air dried lignites and peats containing over 50 per cent of water, then direct gasification becomes difficult, even when thoroughly preheating air and fuel, and we have either to admix a certain weight of dry coal to the raw fuel or we must briquet it, whereupon the commercial distribution radius of the fuel and its range of application is extended somewhat in proportion to its increased heat density, regularity of form and composition.

EFFECTS OF BY PRODUCT COKE MAKING

37 Taking up another phase of the subject: it is through the logical application of approved methods of the utilization of the higher grades of coal to the exploiting of the lower species that we have come to abandon the traditional and wasteful practice of appraising the coal according to its heat contents and of utilizing its fuel value only, but now, before destroying coal we analyse it as to its chemical and other values. We are actually doing the same with peat now that progressive industries did long ago with coking coal in by product recovery ovens.

38 The resulting advantages, it is remembered, for the coke making industry were twofold: An increase of from 5 to 10 per cent in the yield of coke, and a return from the sale of by-products varying from 75 cents to $1 per ton of coke made. Yet some countries even today are reluctant to change their conservative attitudes toward this very rational process. Take the case of England. If the total quantity of coke made in the United Kingdom for metallurgical purposes is reckoned at 20 000 000 tons, at an average price of $3.30 per ton, the general adoption of by product coke ovens would result in a saving of from $1 750 000 to $3 500 000 derived from the increased yield of coke, while up to $20 000 000 could be derived from the sale of the by-products, provided that the intrinsic value of the latter would remain the same in the future as it is now.

39 In Germany by far the largest quantity of coke is now made in modern ovens since owing to the high development of our chemical industries we possess ample markets at home and abroad for the disposal of the by-products which yield us an annual gain of some $10 000 000. We are just beginning to adopt the same process for the utilization of inferior fuels such as lignite and peat, whenever by product recovery can be carried out on a large enough scale to make it a commercial success. Thus peat from the moorlands of upper Bavaria is subjected to a process of destructive distillation in Ziegler furnaces yielding besides coke and gas a number of valuable by-products. The coke is used for metallurgical purposes and as a substitute for charcoal; the gas for heating, lighting and power purposes. Of the chemical by-products sulphate of ammonia is used as a fertilizer in agricultural pursuits; tar oil, creosote and paraffin serve a variety of useful purposes. So what we do in this case is to split up the [illegible] into a number of separate constituents of which each may serve a different purpose and each may fetch a better price than the original material.

COAL TAR OILS

40 Among the efforts made in Germany to derive all products which are necessary to support the national industry from its own native resources and without the aid of foreign imports, the activities in the lignite industry are the most noteworthy. It is remarkable how the production and valuation of this fuel which is commonly known under the name of brown coal has increased within the last fifty years.

41 At the beginning of that period, in 1865, lignite held about the same rank as peat holds now. The State of Prussia at that time produced 18.6 million tons of coal, valued at 25 million dollars, [illegible] million tons of lignite estimated at 3.5 million dollars. By

1905 we find a production of 113 million tons of coal, worth nearly 250 million dollars, and 44 million tons of lignite worth 25 million dollars. The latter figure refers to the fuel value of lignite, not to the price that may be realized from it including by-products such as paraffin and brown coal tar oils.

42 These oils and others gained from hard coal tar, from caking coal and from bituminous slate are getting more and more valuable since it was demonstrated that they can be used successfully as fuel in Diesel and other oil engines. The annual production of paraffin oils gained from brown coal tar has reached within the last year the figure of 40 000 tons, selling at prices from $19 to $26 per ton. The production of oils gained from hard coal tar, such as creosote oil and anthracene oil, amounted to 84 000 tons within the same period and they were sold for purposes of power generation at the very low price of from $6 to $12 per ton, according to locality. Another interesting product of the coal tar industry is benzol. As a fuel it is fast replacing gasolene and alcohol for automobile and motor purposes, since besides costing only half as much it is more economical and safer in operation.

43 The possibility of gaining from lignitic and other coals and from peat a series of substitute fuels for the ordinary crude oil and petroleum is of great importance even for the future activities of the United States, though this country is apparently very well supplied with raw materials of every kind, especially with oil, marching as it does at the head of all oil producing countries with an imposing output worth almost a hundred million dollars per annum.[1]

44 Yet there stands this incontrovertible fact that oil wells have been tapped so recklessly in the past that the center of production was shifted from Pennsylvania to California, the extreme west of the country, leaving little territory for further exploitation. And there is the other fact that the remaining wells are practically all in the hands of one private corporation, leaving little chance for the Government to establish a control of the kind that would prevent said

[1] In considering the relative values of the mineral and metallic products of the United States, it is found that the fuel materials aggregate about $650 000 000 annually, which is nearly double that of the output of pig iron, and about six times the value of the various precious metals produced. Of this enormous sum, which represents about 40 per cent of the total mineral production of the country, only about one-seventh, or $95 000 000, must be credited to the output of oil, while over one-half is represented by bituminous coal, one-quarter by anthracite, and one-twentieth by natural gas. An interesting fact often lost sight of is that the oil output in the United States has a greater total value than silver and gold together.

corporation from selling out such oil immediately and with no regard for future national activities.

45 The enormous extent and the policy of the business which the oil trust has been doing during the last 24 years with the American product can best be realized from the report which the Commissioner of Corporations has recently submitted to the United States Government. Comparing the prices of crude oil with the prices of refined oil and its by-products to ascertain whether the margin between the raw and completed product has been reduced by the improved methods and better organization of the trust, the Commissioner finds that this margin, instead of decreasing, has increased from 6.6 cents per gallon for 1898 and 1899 to 7.7 for 1900 and 1902, and 8.4 cents for 1903 and 1905. Naturally an increase has also taken place in the annual profits of the Standard by reason of this price policy, amounting from 1896 to 1904 to over $27 000 000, while the entire net earnings from 1882 to 1906—based on an investment worth at the time of its original acquisition not more than $75 000 000—were at least $790 000 000, and possibly much more.

46 These figures prove clearly that the beneficial effects of private monopoly power on the national industry and the absence of normal competition are not always what they are claimed to be by their defenders. "The Standard Oil Company," says the report, "gives the public none of the benefits of its superior efficiency, but, on the contrary, charges prices higher than those which would exist in the absence of such a combination." And, we must add, what is worse for America: the rich veins of this colossal country have been emptied of their precious contents—an irrecoverable loss—and the oil, by the manipulations of that company, has been squandered all over the world where it has served and is still serving to support and build up competing industries and skilled talent. In the mean time foreign countries whose natural resources are exploited under the supervision of the government, have preserved their store of oil, small though it may be, and are beginning to lift it now, at a time when its intrinsic value as a raiser of by-products for a variety of industries is being understood, appreciated and duly compensated. It is only when people lack technical training and industrial forethought or when they have nothing but the immediacy of earnings at heart, that they fail to recognize in the gross exportation of fuel materials from a country a dangerous depletion of its basic resources, working injury to the national welfare.

47 The increasing importance of oil in naval activities is known. An ample and ready supply of it for purposes of national defense is

desirable. The event of the utilization of tar oils gained from coal under the control of the Government will prove a more effective restraint to the monopolizing of the oil business by the Standard Oil Company than the appointment of receivers or indictments by the hundred brought by the Federal grand juries against that corporation and the payment of fines exceeding even the thirty million dollar mark.

LIGNITE AND BROWN COAL BRICKETS[1]

48 Another event which is bound to increase largely the value and industrial importance of lignite lands is the transformation of the raw material into brickets. The center of the lignite basin in Germany, which is located on the left banks of the Rhine, has increased its output of raw lignite within thirteen years from 1 016 300 tons to 9 673 100 tons, that is by 851 per cent, and its output of brown coal brickets from 272 580 tons to 2 447 000 tons, that is by 797 per cent. Of this amount 1 810 000 tons are sold in Germany, 291 700 tons are exported and the rest is used in the briquetting industries. Without overestimating the value of statistical figures these data testify well enough to the increasing demand for this class of fuel in European pursuits. The sale of brickets would have been even larger if there had been no car famine.

49 It may be ground for comfort in the United States, where transportation is a serious factor for the briquetting industries to contend with, to know that in a country where the railroads are owned and controlled by the government, being less of a business concern and more of a philanthropic-national institution, such accidents will happen, though with this difference compared to America that they befall large and small dealers alike without discrimination and without secret rebates.

50 The cost of the production of brickets has increased somewhat in proportion to that of ordinary coal, owing to the higher wages paid. For domestic uses they were sold last year at from $2.25 to $2.50 per ton, while for industrial purposes they brought prices from $1.70 to $1.80 per ton. The heat value of brown coal brickets ranges from 7700 to 9600 B.t.u. per pound, compared to an average of 4900 B.t.u. per pound of raw lignite containing 45 per cent water. Their heat density is such that up to 3 tons or 60 000 000 B.t.u. can be stored in a space of 100 cubic feet, hence their commercial distribution range is almost double that of the raw coal.

[1] For distribution and characteristics of American lignites refer to the regular reports of the United States Geological Survey.

51 One drawback to the more general application of lignite brickets in industrial pursuits rests with the fact that the smaller sizes which are best suited for producer work are somewhat more expensive to make and yet bring lower prices than the larger sizes, which are now so widely used for domestic firing. Yet they are an ideal producer fuel on account of the regularity of form and composition. An analysis of Bockwitz brickets, which contain about 80 per cent of combustible matter and represent a fair average, shows C 53.3 per cent, H 4.24 per cent, O+N 21.95 per cent, S 1.06 per cent, H_2O 14.65 per cent, ash 5.64 per cent, slag 1.09 per cent, calorific value 4580 calories per kilogram (8240 B.t.u. per lb.) The gas generated from Bockwitz brickets in (Körting) producers shows an average analysis of: CO_2 14.8, O 0.2, H 16.3, CO 11.8, CH_4 2.0, C_3H_6 + C_2H_4 0.4 calorific value 1030 calories per cubic meter (115.4 B.t.u. per cu. ft.) The briquetting tests of the United States Geological Survey show that the Dakota lignites can be treated as successfully as the German brown coal, a fact which will vastly extend the territory which these fuels control.

52 Producers burning brown coal brickets or dry lignite and peat, unless having means like the Pintsch producer for by-passing the volatile gases through the incandescent zone below where they are burnt, employ invariably a second upper incandescent zone. An additional supply of air preheated to about 200 degrees centigrade, (Deutz), serves for the destruction of the tar, or better, of the tar forming hydrocarbons which are decomposed together with the moisture, so that besides the cleanness of the gas there is a double gain in the calorific value of the gas made. No water need be added when the material contains beyond 20 per cent of moisture. No operative difficulties are encountered so long as the water contents of the fuel does not exceed 28 per cent. Instead of clinker or slag a light ash is formed which is easily removed. The actual coal consumption remains in the neighborhood of one pound per horse power hour delivered, costing about one tenth of a cent.

53 In water cooled producers which can work with a high incandescent zone, using high air pressures and allowing the attainment of high temperatures, raw lignite with up to 50 and more per cent water can be burnt directly without previous treatment. In one [illegible] smelting plant in Germany raw brown coal, containing only 26 per cent carbon, 60 per cent moisture and 30 per cent dust and having a heat value of 2200 calories per kilogram, or 3960 B.t.u. per pound, is gasified in Turk producers, yielding a gas of 1340 calories per cubic meter (150 B.t.u. per cu. ft.).

54 When raw lignite is burnt in producers possessing no provisions for the destruction of tar, and when it is desired to separate out the paraffins from the gas subsequent to its generation in order, on the one hand, to recover the by-products, and on the other, to distribute the gas for heating or power purposes, or both, it is better in large plants, instead of employing any of the well known cleaning apparatus, to press the gas after being cooled down to atmospheric temperature through a motor driven compressor into a double tank whence it is allowed to flow into the distribution main without interruption. The compression and subsequent expansion of the gas will serve very effectively to separate out undesirable constituents, leaving the gas ready for local and other uses in gas engines and furnaces. For the average power plant it is, of course, not advisable to engage in operations entirely distinct from its own special field of work.

THE UTILIZATION OF PEAT

55 If we were to conclude from the manner and extent of the industrial application of peat within the last twenty years to its future possibilities, our prognostications would be both disappointing and wrong. While the use of hard coal within said period has increased in Germany from 60 to 136 million tons, and that of lignite from 15 to 56 million tons, the output of peat has not increased at all, in fact it has diminished. The mistake that has been made is that peat was regarded and utilized as a fuel only and not as a raiser or container of valuable by-products. Peat, since it does not allow of transportation, neither as raw material nor in form of brickets, owing to excessive moisture contents, has no market value. Hence its appraising or valuation depends entirely on the initiative of and on the course of action adopted by the owner of the moorlands. Peat to be rightly used and husbanded must be considered and treated as a material furthering the agricultural possibilities of the soil and not as a means for producing heat, light and power in varied industries, at any cost.

56 Agriculture is the fundamental industry of a country. On its prosperity all other industries are based. Every consideration is subordinate to the idea that the food growing possibilities of the ground must remain in accord with the ever increasing population. The gradual exhaustion of the soil and its territorial diminution caused by the restless expansion of the mechanic industries must be compensated, on the one hand, by utilizing vast stretches of land

hitherto void of cultivation; on the other hand, by supplying an ample provision of nitrogenous manure preferably from the country's own native resources.

57 It is a frequent occurrence accompanying ordinary coal mining operations that the soil above the mines will sink and decay, becoming what we call "unland," that is, territory unsuited for agricultural pursuits. When digging peat good farm land is laid bare to the plow ready for immediate cultivation and settlement, thus causing new agricultural possibilities and values to develop. When reclaiming land covered with timber or having stumps upon it, 1 000 000 acres would cost at least $33 000 000 to clear. Peat moreover, contains from 0.75 to 2.85 per cent of nitrogen which can be recovered by proper treatment as ammonium sulphate, giving an excellent fertilizer.

58 Until a short while ago all countries were dependent for their supply of nitrates on the salpeter resources of Chile, which will be exhausted in about forty years. Lately the production of sulphate of ammonia gained in the different countries has replaced the imports of Chile salpeter to a large extent. In 1895 the consumption of imported nitrates in Germany was about 450 000 tons and that of sulphate of ammonia 100 000 tons. Ten years later, in 1905, the former rose to 540 000 tons and the latter to 215 000 tons, or 20 per cent and 100 per cent respectively. Yet the value of the annual imports of nitrogeneous manure which is supplied to that country in form of saltpeter, sulphate of ammonia and guano from abroad amounts still to a total of some $36 000 000, which can be saved by the judicious application of up to date methods. The recovery of the nitrogenous and other by products is the first essential for a rational utilization of peat.

59 Among the technical difficulties which are encountered must be mentioned first the low heat density of peat caused by the high moisture and high ash contents, which vary around 90 and 25 per cent respectively. By the use of kneading and molding machines and air drying, the moisture may be reduced down to about 25 per cent. There are other methods of drying peat, for instance the electrical process invented by Graf Schwerin and others, that give more economic results than the mechanical process, but they cannot here be discussed in detail.

60 Another technical difficulty of peat utilization is the cumbersome task of dredging and transporting the raw material from the moorlands to the place of usage. This distance increases daily owing to the low heat value and depth of peat bogs. Even when

located in the midst of moorlands an industry that would base its operations solely on peat as a *fuel* would soon find in the cost of haul ing a limiting condition, also in the fact that this very voluminous material cannot very well be stored so as to be protected against the influence of the weather, and if exposed to the atmosphere it will slack and disintegrate quickly.

61 Attempts to use peat for firing locomotives have failed abroad. The practical question: what does it cost to raise 1000 pounds of steam with peat compared to coal firing, has been decided by Dr. A. Franke, the foremost authority on peat utilization, in favor of coal. So here comes the gas producer as the only economical solution of the problem.

62 Peat with 50 and more per cent water is now gasified in producers with the aid of highly superheated steam (Dr. Caro's patents), yielding, besides sulphate of ammonia, a power gas well suited for use in gas engines. A plant of this kind is operating near Nordgeorgfehn, in Germany, using peat from the Marcard moor-canal, which contains 1.17 per cent of nitrogen. Per ton of dry peat 30 kg. of sulphate of ammonia worth $1.70 and 2500 cubic meters (88 250 cu. ft.) of gas of 146 B.t.u. are gained, which will yield 600 horse power hours in gas engines besides what is used in the process. From the gas driven electric central station current is distributed to the neighboring districts at low·prices. Some peat bogs in Ireland contain in their upper, more recent layers, up to 3 per cent of nitrogen. This means that 2 tons of wet peat could yield on an average nearly as much ammonia as 1 ton of coal. To the Mond interests the possibility of using peat instead of slack fuel in producers comes as a very welcome event since it will help to place this process on a commercial footing also in this country.

63 Reference has already been made to the Ziegler process which originated from an attempt to improve the raw peat so as to give a better fuel. Now the idea is to make coke from peat and to utilize the resulting by-products in the most profitable manner. In order to accomplish this, peat with low ash contents and with its moisture expelled down to 18 or 25 per cent as a maximum must be available. There are two systems of closed ovens or retorts employed, the one yielding a good metallurgical coke and the other one of the semivariety. The analysis of coke No. 1, of which are gained from 8 to 10 tons per oven within 24 hours, is: C 87.8 per cent, H 2 per cent, N 1.3 per cent, S 0.3 per cent, O 5 per cent, ash 3.2 per cent, calorific value 7800 calories per kg. (14 040 B.t.u. per lb.) Of semi-coke are gained from 12 to 14 tons per oven within 24 hours, and the analysis shows

C 73.89 per cent, N 1.49 per cent, S 0.20 per cent, H 3.59 per cent, O 14.52 per cent, ash 2.5 per cent, moisture 3.8 per cent, heat value 6700 calories per kg. (12 060 B.t.u. per lb.) Among the more valuable by-products of the tar are acetate of lime, sulphate of ammonia, methyl alcohol, light and heavy gas oils, which can be used partly as fuel and lighting oils and partly as lubricants, and paraffin and asphaltum. There are several plants of this type working in Germany and elsewhere, the most notable of its kind being the one built on the moorlands of upper Bavaria, at Beuerberg. It is a most interesting illustration of the modern endeavor to secure in the utilization of coals the largest returns from the lowest grade of supply.

MINE CULM, WASH BANKS, ETC.

64. The rational utilization of these materials is of great importance for collieries, where they are available in enormous quantities, and where they have formed hitherto a real nuisance to the works management. Owing to excessive ash contents these banks could not be burnt under boilers, nor could they be dumped back into the mines on account of the danger of causing self ignition of the remaining coal deposits. So they were either stored up in huge piles in the neighborhood of the pit or, where territorial limitations prevented this, they were transported by rail into neighboring dumping grounds, being thus absolutely useless and causing heavy expenditures. There are two possibilities of utilizing these low grade coals: one is to gasify them in Mond producers where their fuel value is utilized, they having 30 per cent combustibles yielding a gas free from tar and well suited for heating, lighting, or power purposes. A plant of this type was built early in 1902 on the von der Heydt coal mines, Saarbrücken, Germany, and has been in active service ever since. The gas generated has an average composition, in per cent of volume: CO_2 [illegible], CO [illegible], CH_4 0.9, H 27, O 0.57, heat value (low) 1183 calories per cu. m. ([illegible] B.t.u. per cu. ft.) The cost of 1000 B.t.u. in form of producer gas is only 0.005 cent, or one brake horse power hour in gas engines costs 0.05 cent.

65. Another method is that developed by Dr. N. Caro, of Berlin, Germany. It is based on the observation that "wash banks" and other waste contain more nitrogen than that which corresponds to their coal contents. In Westfalian collieries it was found that wash banks, the coal contents of which show on analysis about 1.2 per cent of nitrogen, contain up to 1 per cent of nitrogen, though their total contents of combustible matter is only 25 or 30 per cent.

Dr. Caro has succeeded in gasifying this material in producers of the Mond type especially equipped for the purpose, and besides getting a suitable gas he gains about 80 per cent of its total nitrogen contents in the form of sulphate of ammonia. At the same time the sulphur is removed so that the residues of the gasification process can be directly dumped from the producer into the mines without fear of premature ignition. Per ton of wash banks, depending on their value, from 30 to 40 kg. of sulphate of ammonia are gained so that not only the cost of removing the waste coal is recovered but, in addition, a good profit is realized.

COKE BREEZE, DUST COKE, ETC.

66 There are places where fuels of very small size are available in large quantities and at low prices, for instance in gas and coke works, railway stations, etc. Their high ash and dust contents and the small size makes them unfit as boiler fuel, nor are they well suited for transportation. Two ways of utilizing these coals are now open: The one is to burn them in gas producers especially designed for their use; the other is to briquet them, whereupon they become capable of competition with the best grades far and near. Here are some of the points to consider when using dust coals in gas producers: The great resistance offered by the dense fuel material to the passage of air must be overcome by keeping the charge as low as possible and constant and uniform in height, otherwise the air will pass up along the walls, producing clinkers and a bad quality of gas. The coal must be charged frequently within short intervals and in small quantities, and if containing moisture, it must be preheated by the gas as produced. This exchange of heat will increase the calorific value of the gas at the same time lowering its temperature and that of the process. Producers must be dimensioned larger in proportion to the higher dust content of the material used. The quality of gas rendered is somewhat lower but sufficient for use in gas engines and for heating furnaces, unless very high temperatures are desired.

67 Producers designed in accordance with these principal considerations by Julius Pintsch, of Berlin, and by the Gasgenerator Company, of Dresden, Germany, have given excellent results with the poorest fuels. A 1000 horse power Pintsch producer plant using coke breeze has been doing uninterrupted service, day and night, since April 1905. The dust coke which settles in the smoke boxes of locomotives, having a composition, in per cent, C 75.2, H 0.4, O + N 1.45, S 0.85, ash 19.2, moisture 2.9, calorific value (low) 6073 calories per kg. (10 930 B.t.u. per lb.) can also be used in these producers

[illegible] following composition, in per cent: CO_2 5.0. [illegible] calorific value (low) 1100 calories per [illegible]

[illegible] the intrinsic value and the salability of [illegible] briquetting, the case of the Gas Works [illegible] Large piles of dust coke which originated [illegible] handling, storing and transporting ordinary good [illegible] They had been sold hitherto as filling materials [illegible] price of 2.5 cents for 100 pounds, while coke in [illegible] would sell at 30 cents per 100 pounds in that locality. [illegible] coke contained from 75 to 80 per cent of combusti[illegible] impossible to use it for firing boilers since the fine dust [illegible] up the flues requiring frequent cleaning and causing heavy [illegible] So a briquetting machine was installed which pro[illegible] 1000 brickets of 0.4 kg. or 400 kg. (880 pounds) of brickets per [illegible] An addition of 5 per cent of hard pitch and tar residues as [illegible] material gave sufficient cohesion. The average production [illegible] hour day was 4200 kg. (9240 pounds) of brickets having a [illegible] value only 5 per cent lower than coke, the higher ash contents [illegible] compensated by the greater heat value of tar and pitch. They [illegible] an excellent fuel for boilers and gas producers. By the adop[illegible] superior methods of utilization the returns from this low [illegible] material have been increased from 55 cents realized per ton of [illegible] to $3 received per ton of coke brickets.

[illegible] A few words may be added regarding the activities of the United States Geological Survey and the proposed control of coal lands by the Federal Government.[1] In view of the paramount importance of the subject it is a matter of regret for the development of this branch of industry in the United States as well as for science [illegible] noting the inadequate apparatus available at the fuel testing plant at St. Louis and considering the superior progress that has been made in the study of these commodities abroad—that the appropriation for the investigation of fuel problems which has been

[1] [illegible] committee of twenty experts chosen by the National Civic Federation [illegible] investigation of municipal trading in the United States and [illegible] Britain have come to the conclusion that America, for various well under[illegible] reasons, is unripe for municipal ownership of the revenue-producing indus[illegible] [illegible] draw the further conclusion that it is ripe for government control [illegible] natural resources. In Europe the method of partial ownership of [illegible] corporations has proved very successful.

It has the advantage of effective public control while retaining the stimulus of private interest. The private stockholders can be relied on to prevent political abuses, and the public ownership assures the necessary publicity.

made by Congress may not be expended for work outside the United States proper. A more liberal endowment of the work of the Geological Survey which would enable that body to proceed with the investigation and dissemination of fuel characteristics and conversion beyond the limits of its present equipment must seem desirable for the future stability of the American industry.

70 The accumulated experience of many European nations that have attempted, from time to time, to operate industrial establishments, bureaus of research and other offices under the supervision of the State, proves conclusively that when a government undertakes to own or to control institutions devoted to the public welfare and fails to supply the means necessary for bringing them up to the highest standard of excellence and for keeping them at that level it will work harm both ways. It discourages those that have devoted their best energies to the work and in the routine of labor find their efforts hampered by insufficient equipments and by pecuniary restrictions, and it destroys the faith of those among the people who do not profit by it in the efficiency of government control as a means for promoting the industrial progress and for furthering the general prosperity of the country.

IN CONCLUSION

71 This subject of which the above gives a brief *exposé* does not allow of narrow technical treatment. It requires breadth of vision and accuracy of knowledge to realize its economic and political bearing on the destiny of nations. One fact however stands out clearly: it is this that, according to the present state of our knowledge, the rational utilization of coals of high volatile contents requires the adoption of gas producers with by-product recovery and the distribution of heat, light and power from gas driven central stations to the neighboring districts, a scheme which is feasible only when operating on a large scale and where staple markets for the disposal of goods lie within the commercial distribution radius of the plant. Fuels of high ash contents, on the other hand, such as mine culm and other waste of low heat value, must be used at the spot in producers specially equipped for the purpose. Dust coals and similar fuels can either be gasified in producers particularly designed for their use, or they may be transformed into brickets, whereupon competition becomes possible with the best grades of coal for all manner of application. In all cases the employment, in the electric central station, of large gas engines is a logical supplement to the gasifica-

[illegible] means, so far available, [illegible] in the operation of [illegible]

[illegible] to see revealed is that [illegible] has passed beyond the [illegible] Siemens, which he [illegible] I am bold enough to [illegible] for any purpose [illegible] judicious and economic [illegible] producer, in which coal is [illegible] gas and coke, as is the case [illegible]

DISCUSSION

[illegible] The national importance of utilizing [illegible] fully realized. Furthermore, it [illegible] realized and proved that even these very low [illegible] gasified in the producer, and that the producer [illegible] desirable possible substitute for the boiler. [illegible] shown and it is important for us as mechan- [illegible] is not having been shown is the fact that [illegible] grade fuels is not today in this country a [illegible] can be gasified, but I say it is not a [illegible] I can support that on three bases.

[illegible] these very low grade fuels will be a [illegible] plant can be built at all. An ordinary [illegible] anthracite buckwheat coal, which may [illegible] this sort of work, will cost more than [illegible] considerable margin; and first cost is a matter [illegible] American power producers. If, there- [illegible] at all which I doubt—a plant for [illegible] very low grade fuels, it will cost a great deal [illegible]

[illegible] the moment that it could be bought. [illegible] labor of operating it excessive. I have [illegible] that is not at all considered a low grade [illegible] for the firing alone, three and a half [illegible] producer as anthracite buckwheat did. [illegible] for the latter. That is the second [illegible] gasification process is not yet commercial.

5 The third reason I consider even more important than the other two, namely, the fact that in present producers there is a limit to the length of run possible, after which they must be shut down and cleaned out. That means that you must carry, if you need power continuously, a large number of spares, a number to be determined by the length of the run possible in each and that in turn by the fuel characteristics.

6 I think, however, that everybody, even remotely connected with the gas engine or gas producer enterprise, is at work on this proposition, experimenting, inventing and calculating, and I have no doubt that, with the concentration of energy the subject is now receiving, the solution of the problem is not far off.

Prof. R. H. Fernald In view of the trend of the discussion especially that portion taken up by Professor Lucke, I want to bring out two or three points.

2 First, as to the rate of development of the gas producer for power purposes A year ago there were approximately one hundred and fifty producer gas installations in the United States; at the present time there are over four hundred, the number having been more than doubled in the past year. Of the four hundred installations, about 15 per cent of the total number is operating on bituminous coal and 85 per cent on anthracite. The aggregate horse power represented by these installations is approximately 130 000. Of the aggregate horse power, about 70 per cent of the total is on bituminous coal, although the larger number of installations is operating on anthracite coal. The anthracite plants average about one hundred horse power each and the bituminous plants about sixteen hundred.

3 It was stated that the gas producer plant was more expensive than the steam plant. For plants of less than 1000 horse power the gas producer installation, including gas producer, engine and electric generator, costs from 15 to 30 per cent more than the corresponding steam plant. This difference can be made up by the saving in the cost of operation in approximately two years' time with coal at $2.75 a ton. With plants from 1000 horse power up to 5000, the difference in first cost is approximately from 5 to 15 per cent in favor of the steam plant, and the difference can be made up in approximately one year, with coal costing $2.75 a ton. With plants from 5000 horse power upward, the initial cost of the two types of installation is about the same.

4 A gas installation under construction at the present time—a 5500 horse power plant —has an estimated cost, including producers,

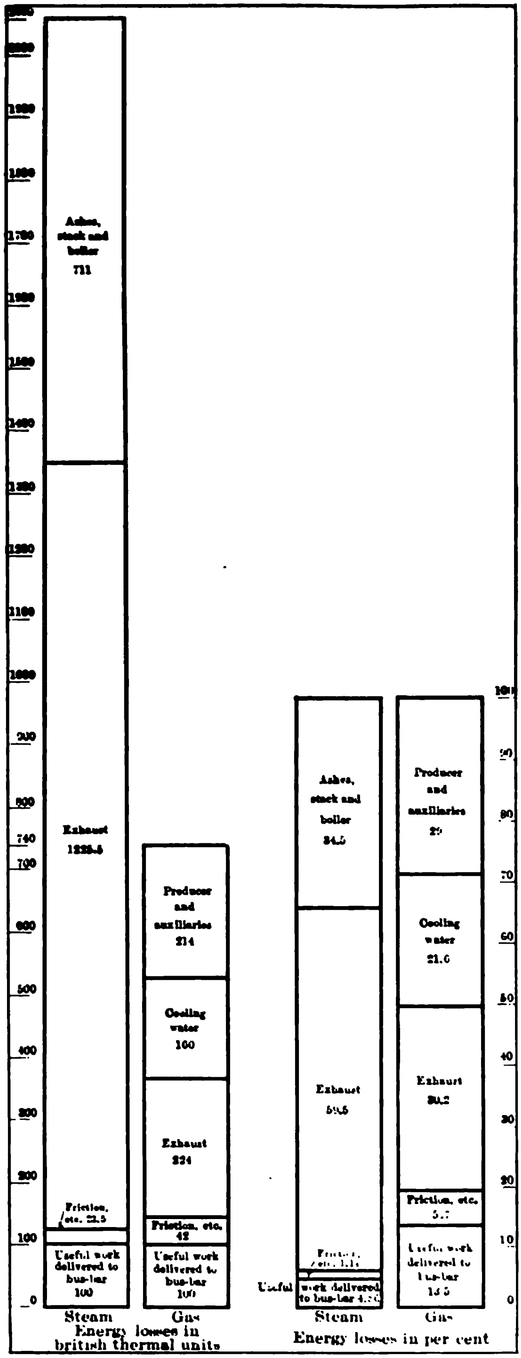

FIG. 1 RELATIVE ECONOMIES OF STEAM AND GAS POWER PLANTS

engines, electric generators, buildings and auxiliaries, all erected, together with freight, of $73 a horse power. The corresponding bid for the steam plant was stated to be $74 a horse power, $1 higher for the steam than for the gas plant.

5 The next point that I desire to bring out is the relation between the amount of coal required in a steam plant and in the corresponding producer gas plant. Fig. 1 represents the relative quantities of coal required by the steam and producer gas plants at the Government

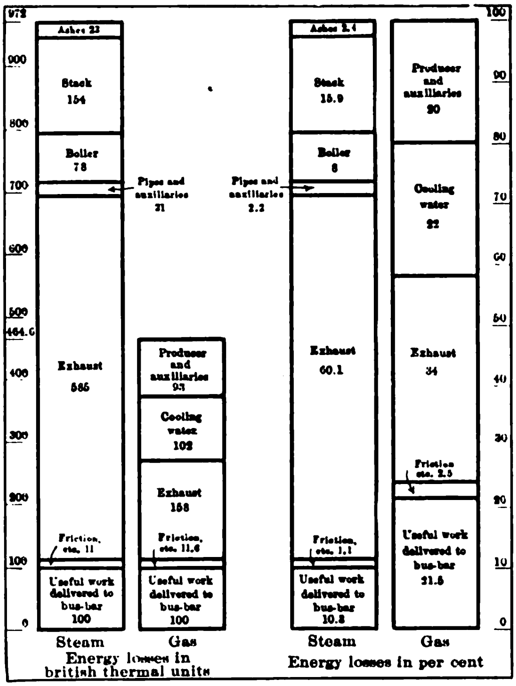

FIG. 2 RELATIVE ECONOMIES OF STEAM AND GAS POWER PLANTS

Testing Station. At the left of this figure is shown the number of British thermal units that must be delivered in the fuel to the furnace and producer of the steam and gas plant, respectively, in order that 100 British thermal units may be converted into electric energy. At the right is shown the percentage of useful work at the bus bars for the plants considered.

6 In considering the relation between the economic results of the two types of plants under discussion, that is, steam and producer gas, attention is called to the fact that in the ordinary manufac-

[illegible]

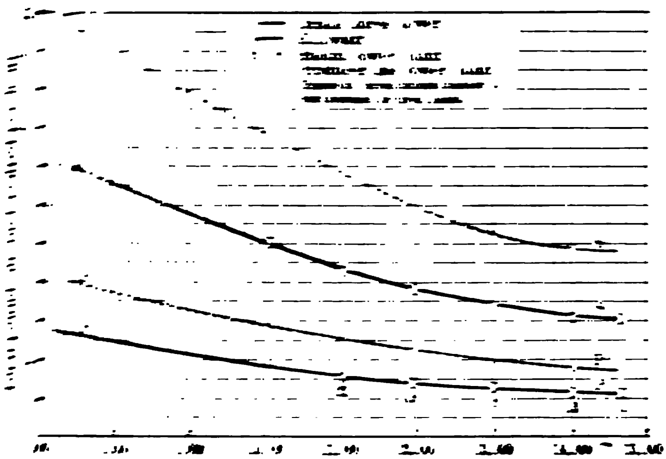

FIG. 3 COMPARATIVE POWER PLANT DUTY

[illegible] Pounds of Fuel per [illegible] 77 Bituminous Coals and 5 Lignites at Full Load 255 B. H. P.

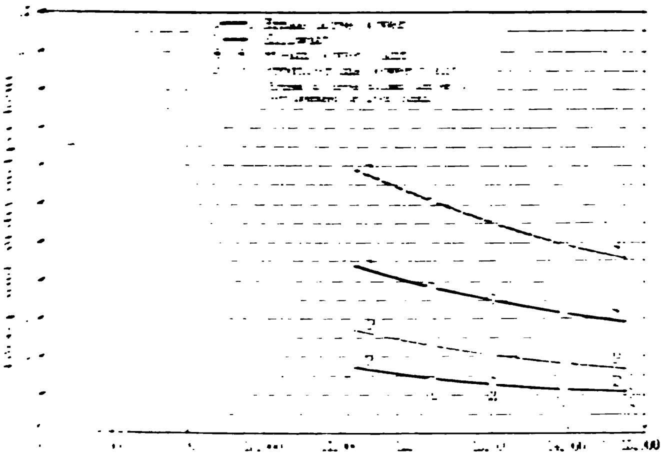

FIG. 4 COMPARATIVE POWER PLANT DUTY

[illegible] Pounds of Dry Fuel [illegible] 77 Bituminous Coals and 6 Lignites at Full Load 255 B. H. P.

gas plants of exceptional efficiency. The data of the steam plant selected for this comparison are from the figures presented by Mr. [illegible]ott, Superintendent of Motive Power, Interborough Rapid Transit

Company, New York. This plant is one of the best designed and most economically operated in this country and shows a thermal efficiency of 10.3 per cent. Various writers state the thermal efficiency of producer gas plants to be as high as 33 to 38½ per cent, and some give figures as extravagant as above 40 per cent. Although the intention is to present figures for a producer gas plant which may compare favorably with those of the steam plant mentioned, an effort has been made to keep well within conservative efficiencies. Attention is also directed to the fact that the producer gas plant considered should be of such size as to compare favorably with the steam plant. This precludes the suction plants which are of relatively small size

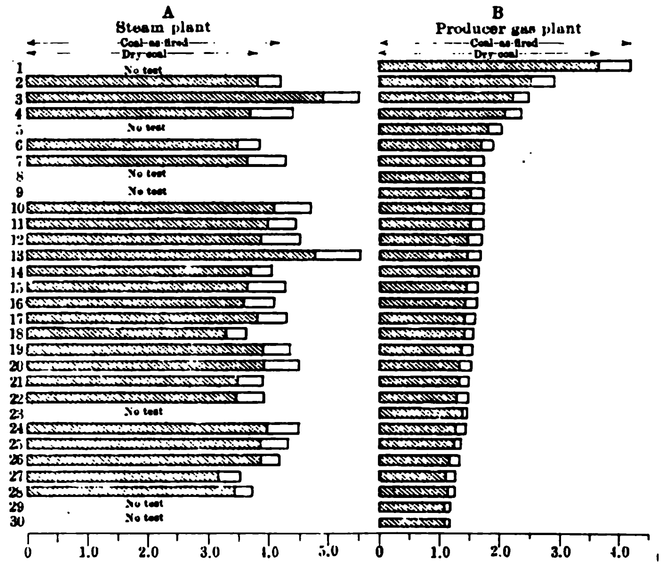

FIG. 5 POUNDS OF ILLINOIS COAL PER BRAKE HORSE POWER HOUR

but which give higher thermal plant efficiencies than the larger pressure and down-draft plants which require more or less auxiliary apparatus.

7 Although it might be possible to find a producer gas plant of higher thermal efficiency than the one used in the comparison shown in Fig. 2, a careful study of the problem has led to the use of a reasonably conservative figure, that is, 21½ per cent for the producer gas plant as compared with the 10.3 per cent of the steam plant. Another method of showing the economic results from the Government Testing Station is presented in Fig. 3 and 4. The ratio is brought out more clearly perhaps by reference to Fig. 5, which shows the results secured

	Fuel from		
1	New Mexico	[illegible]	[illegible]
2	Tennessee	[illegible]	[illegible]
3	Iowa	[illegible]	[illegible]
4	Wyoming	[illegible]	[illegible]
5	Illinois	[illegible]	[illegible]
6	Wyoming	[illegible]	[illegible]
7	Donald [illegible]	[illegible]	[illegible]
8	West Virginia	[illegible]	[illegible]
9	West Virginia	[illegible]	[illegible]

from a large number of different Illinois coals. In some instances no steaming test was made, as the coal was of such an inferior quality that it could not be handled under the boilers, due either to the fineness of the slack coals or to the high percentage of sulphur.

8 The third point which I desire to emphasize is the fact that certain low grade fuels have been used with marked success in the producer gas investigations at the Government Testing Station. The accompanying table shows the results from nine fuels in which the percentage of ash is relatively high. In the case of No. 9, West Virginia bone coal, the refuse was in the form of slate and rock and in many instances sparks were displayed when the rocks were struck by a hammer. Even with this exceptionally low grade fuel the consumption per horse power hour is seen to be remarkably good. Some of the lignites might be added to this list on account of their high percentage of moisture. For example, a North Dakota lignite on which very satisfactory results were secured contained approximately 40 per cent of moisture.

9 I mention these results from low grade fuels to show what work is being done in the United States along the line of their rational utilization. I recognize the fact that it may be claimed by some that the Government Testing Station is not a commercial plant. While this is, of course, true yet one opportunity only has been given the gas producer crew to secure results from each of these fuels. From our standpoint, the bone coals and the other fuels indicated can be regarded as commercially possible in the gas producer, and they can undoubtedly be operated with exceptionally good economy in the majority of cases. It should be emphasized that the producer upon which these tests were made was designed primarily for anthracite coal and that no change was made in the construction of the plant for the tests recorded in this discussion. The fuels mentioned were received at the plant at various times during the past three years and were tested in the order in which they were received, together with all the other fuels, without reference to the percentage of ash, sulphur, moisture or other properties. Over one hundred and fifty bituminous coals, lignites and peats have been thus tested in the gas producers at the Government Testing Station.

MR. EDWARD J. KUNZE Comparison has been made between the large size boiler, with all its refinements, and the hand fired, hand tended gas producers. It has been said that the cost of attendance is greater for the producer than for the boiler. This comparison is not fair. There is no reason, in large plants, why we should not have our producer automatically stoked and the ash automatically removed and this is indeed the only proper way of attending a large number of large producers. To be sure, we are encumbered with the extra cost, due to the refinement, but do not superheaters, economizers, automatic stokers and ash conveyors attached to boilers also cost money?

2 If the fuel and ash are handled in as rational a manner in our large producer plants as they are in our large boiler plants, we may expect the labor cost to be very nearly in proportion to the amount of fuel burned and, therefore, for the producer, it should be at least one-half that for the boiler plant.

3 We have seen that we are to depend more and more, in the future, on the use of inferior fuels, many of which have a great tendency to form clinker. The effect of clinker formation on an ordinary grate is to reduce the effective grate area and to cause uneven heating and cooling of the grate bars with its attendant evils. The herring-bone grate is not the proper type of grate upon which to burn a clinker-forming coal. In order to prevent clinker formation, the most rational thing to do is to agitate the fuel bed slightly. The inclined grate will not do this properly. In burning a clinker-forming coal on an inclined grate stoker, the tendency is for the coal to roll down the incline, adding to its size as it rolls, much as a snow ball does in rolling down hill, leaving more or less thin or bare spaces behind it. Especially is this true where the boilers are pushed very hard, because of the greater incline given to the grate under those circumstances. A more rational sort of grate for this purpose would be a chain grate having oscillating grate bars. The occasional movements, up and down, of such a grate during its passage would not only prevent the formation of clinker of an objectionable size, but such oscillations would also keep the fuel bed and grate free of ash, and the tendency would be toward a more constant air space.

4 Common slack coal may be very successfully burned on such a grate, and the burning of culm meets with success if a proportion of bituminous coal is added. Of course the grate should be designed for the fuel to be used.

5 The fuel bed should be kept compact. This may be done by causing the ash to be pushed over a bridge wall in the rear of the grate. It is not proper to allow the caked fuel to tumble over at the end of a chain grate and break off, much as do icebergs from their mother glaciers, leaving crevices in their wake. No cool air should pass up behind the grate. All air should pass through the grate and up through hot coals, not through open places in the rear.

6 In the producer, clinker formation presents a far more serious aspect. Here we desire to generate a gas of uniform quality. When clinker forms in a producer, the coal around its outer edges burns rapidly, leaving weak spots for the more easy passage of CO_2, air, H or other gas, hence uniformity of quality is sacrificed.

7 This trouble may be overcome in the manner indicated above, that is, by agitating the fuel bed. Poking the bed tends to pack it unduly and unevenly. Vertical stirs would cause open or at least weak places to occur in their wakes through which air, etc., may more readily pass. The proper method of stirring would therefore seem to be that in which horizontal stirrers are used, and these should have a sufficient rake in order to cause the fuel bed to be slightly lifted. Especially is this true where the down draft system is employed, on account of the greater tendency to pack.

8 The principal reason for admitting steam under the fuel bed is to break up clinker. This function is performed by the time the ash pit is reached, but it is important that at no stage preceding that of the ash pit should clinker be formed.

9 A matter requiring an even more careful consideration in the utilization of poor fuels in producers, is perhaps that of the sulphur contents in the fuel with the attendant destruction of pipe lines due to the formation of sulphurous acid when the sulphur gas given off comes in contact with water. But even this may be overcome, either by preventing contact of the gas with water and resorting to dry purification or, if the proportion of sulphur present is not too great, by adding the iron-oxid-sawdust "wash" to one or more trays in the purifier.

10 Reference has been made to the inability to get large overload capacity in the gas engine unit, and while this subject may be irrelevant to the matter under discussion, I cannot refrain from saying a few words in defense of the system.

11 I will grant that we cannot get high overloads in gas engine units. Gas engines are commonly rated at 15 per cent overload, while the steam engine and turbine give very high overloads. The restriction, in the case of the gas engine, is due to thermodynamic reasons and in the Otto or Clerk cycles, at least, we may expect little relief in the future, but need this deter us from taking advantage of its many other exceptional features?

12 The inherent thermal advantages of the gas engine can never be approached by any form of steam motor, and if the gas generating apparatus and engine receive rational treatment in their design, we

may expect the required floor space to be much reduced and this may likewise be said of the cost.

13 The most rational way therefore to take advantage of the good points of each system would seem to be in designing the different units for the functions we desire them to exercise. This would call for gas engines for the uniform loads and steam turbines for the fluctuating loads, in plants having large fluctuating loads. By this dual source of power we would also be at liberty to extend our refinement. The jacket water used in the gas engines could be fed to the boilers. The exhaust gases from the gas engines could be cooled by passing through an economizer and the cooling water used for boiler feed, with the added result that we would not be troubled by any noise of exhaust.

Mr. Romyn Hitchcock[1] The heat value of gases obtained from fuels containing much water and ash is surprising, particularly in view of the natural presumption that with low grade fuels in a producer it would be necessary to pass a considerable excess of air through the apparatus to maintain combustion. It is difficult to understand how the necessity can be avoided when a fuel contains a considerable proportion of ash. The gasification of peat containing 50 per cent or more of water with the production of 2500 cubic meters of gas of 146 thermal units is certainly remarkable. Presumably the gas carries a considerable proportion of both hydrogen and nitrogen, the presence of the latter making the gas suitable for gas engines but less desirable for heating. For while lean producer gas of suitable composition permits of most effective transformation of heat energy into power in gas engines, such gas is not relatively more desirable for steam generation than an inferior grade of solid fuel, and Mr. Junge refers to investigations which indicate that coal with 40 per cent of ash is not adapted to this purpose.

2 The heat values of gases, as shown by chemical composition, are not always proportionally available in practice. In furnaces we have to consider primarily flame temperatures and the concentration or distribution of heat. As regards combustion temperatures there is not very much difference between hydrogen and carbon monoxid, for while a pound of CO burned to CO_2 generates 4325 thermal units and a pound of H burned to H_2O, 62 000, a cubic foot of each of these generates respectively only 319 and 327 units, and both require the same volume of air for combustion. A gas of low heat value may carry sufficient heat energy if it were available, to run a furnace

[1] New York.

or a steam plant, and yet be practically useless for the purpose unless pre-heated by regenerators, being in this respect like the coal referred to containing 60 per cent of combustibles. Perhaps, therefore, the assumption that the economic solution of the problem of firing locomotives with peat or low grade fuels is to be found in the use of gas producers, is not well taken.

3 If the sensible heat of gas from a producer cannot be utilized when the gas is burned, it would seem to be desirable, for all purposes except gas engine work, to increase as much as possible the volumetric heat value of the gas. To this end the endeavor should be to utilize the hydrocarbon constituents of fuels by converting them into fixed gases. A practicable means of producing gas from low grade fuels containing hydrocarbons of sufficient heat value to permit of distribution for some distance, would be most important. Perhaps in this country there is a more promising immediate field for the application of such a process than there is for the general utilization of the distillation by-products, although it is not to be supposed that this condition will long continue. The proposal to make coke from peat and to utilize the by-products is exceedingly attractive. In this case, I understand, the by-products are of a nature to find a ready market, and the process is deserving of earnest consideration.

Prof. Wm. Kent It is a great benefit to the future industries of this country that such men as Mr. Junge are making a study of gas producers and gas engines. While I believe that such a study is bound to eventuate sometime in the utilization of these low grade fuels, I also agree with Dr. Lucke that it scarcely seems to be a commercial proposition at this time.

2 Mr. Junge quotes a statement from Dr. Siemens to the effect that raw coal should not be used for any purpose whatever, but that it should be first converted either entirely into gas or into gas and coke. That statement was made by Dr. Siemens a long time ago, and a great deal of money has been lost by men who followed his ideas and attempted to run boilers with producer gas.

3 Over twenty years ago, a gentleman who had been misled by what Dr. Siemens said, told me that he was going to change his steam boiler plant over and was going to run his boilers by gas producers, and I predicted that he would fail in the attempt, which he did. There is no better way to run a boiler than to burn coal in a furnace either underneath or immediately in front of the boiler if it is burned with the proper supply of air.

4 In regard to the possible competition of gas producer and gas

engine plants with steam engine plants, I had occasion a few months ago to witness a test of a 600 horse power Babcock & Wilcox boiler which was driven to between 1000 and 1200 horse power and fed automatically. The results were remarkable; stack temperature not very high, great overload capacity, a large steam and unusually high economy of fuel, considering the heavy load turbine occupying very little space and running at a very small cost for labor. I remarked to a friend who stood by "This postpones the day of the gas engine," and he replied, "Yes, it does."

5 There is no engineer in the world today who would attempt to duplicate a 10 000 horse power steam turbine unit with a gas engine plant with the same first cost or with the same labor cost. It might be possible to save a little on fuel, because the gas engine is theoretically more economical than the steam engine; but taking the combinations all in all, it is very difficult to see how the advantage of steam can be overcome. At the same time there is an enormous field for the gas engine, and I expect great results from it in the future. I do not, however, like this idealizing of the subject, as Dr. Siemens did, and predicting that the gas engine and gas producer are going to wipe out the steam engine.

Mr. C. G. Atwater In connection with the use of producer gas, Mr. Junge brings out briefly a point in producer gas firing that has not, perhaps, received all the attention it deserves. Where such gas is made in large quantities and transmitted any distance, it is essential that it should be sufficiently cooled to remove the moisture. The writer recalls distinctly a large installation of producers designed to provide producer gas for furnaces of peculiar construction, in which entirely inadequate provisions were made for cooling the gas. The consequence was that the gas arrived at the furnaces at about 80 degrees fahr. and contained so much water and tar that the heats produced were very unsatisfactory. At another plant, opportunity was given to observe closely the results of cooling producer gas. The cooling in this case was done with a coke scrubber having several trays over which cooling water was sprinkled. On warm summer days, when it was difficult to get the temperature below 80 degrees fahr., the heat fell off. On colder days, when the cooling was more efficient, say down to 60 degrees fahr., the heats were maintained with ease. As the curve of saturation with water vapor changes direction rapidly about these temperatures, a relatively small reduction in temperature eliminates considerable water, and thus adds to the efficiency of the gas.

2 In his discussion of coal tar oil, Mr. Junge refers to benzol as a product of the coal tar industry. This is correct in part; but, as a matter of fact, the main source of benzol is not the coal tar industry but the gas from by-product coke ovens which has already been deprived of its coal tar. The coal tar plants do recover a certain amount of benzol, but their output is small compared with that produced from the coke oven gas. Although the use of benzol as a fuel is on the increase in Germany, particularly in combination with alcohol, it has hardly received any attention at all in this country for such purposes; its uses here are confined almost exclusively to the enriching of coal gas and to chemical manufacture. The current English price of 90 to 50 degrees benzol in large quantities is about 9d. an English gallon or 15 cents a U. S. gallon, and these prices may be said to apply also in Germany. The calorific value of benzol of the commercial 90 degree test is about 18 000 British thermal units per U. S. gallon, or about on a par with gasolene.

3 The production of benzol in Germany is about 10 000 000 gallons per annum chiefly from by-product coke ovens, and it may be questioned if more than half of the coal coked in Germany is treated for benzol recovery. The amount of coke produced in Germany is given as 22 287 000 net tons in 1906, whereas the United States production of coke for that year was 36 401 000 net tons, more than one half as much again. Yet our recovery of benzol is so small as to be practically negligible. It is quite possible, therefore, that the development of the portable internal combustion engine may depend as much on the recovery of benzol in the future as upon the extent to which denatured alcohol is manufactured, in view of the diminishing supply of the gasolene now almost exclusively used.

4 Mr. Junge brings out in an interesting manner the advantages that the producer has for the treatment of fuels carrying a high percentage of ash. This is a point that we in the United States, where high-grade coal is so plentiful, have given but little attention. It is a fact that the ashes from the domestic fires of a large city burning mainly anthracite coal contain as high as 50 or 60 per cent of combustible matter, and it is far from being an idle dream that this waste product might readily be treated by some simple washing process and the resulting fuel brought to a better purpose than the filling in of mud flats. It is probably in this high fuel content of ordinary ashes that the promoters of the so called ash burning compounds have found sufficient success in their experiments to entrap the unwary. Indeed the high content of combustible in ashes is by no means unknown to many industrial plants, particularly where bituminous coal is gasified

the requirements mentioned are to be met, then all and not one or two of these operations should be performed mechanically and continuously.

4 The government tests at the St. Louis Exposition show that the average ton of bituminous coal tested contained 310 pounds of tar. In other words, 20 per cent of the energy in our common fuels is in a form that cannot be utilized at all for power gas in the ordinary type of producer. This would seem to suggest the down-draft type, in which the tar is converted into producer gas. The down-draft type, however, presents additional problems which are difficult to overcome in a hand operated producer.

5 In almost all lines of modern industry we find automatic machines that take in raw material at one end and deliver a continuous stream of finished product at the other, while what waste there is passes off by itself. Eventually, I believe, a gas producer will be evolved for large units that will take in fuel mechanically and deliver automatically and continuously an even flow of good gas and a constant stream of ashes.

6 A good boiler-stoker serves as an automatic feed, an automatic agitator and an automatic ash remover. If it is advisable to perform all these operations mechanically for a simple grate fire that is plainly visible and easily accessible, how much more desirable it is in a large gas producer where complicated conditions are continually arising; where the fuel bed is ten times as deep, and is neither visible nor accessible. An even, uniform fire under a boiler is desirable; but an even, uniform quality of gas for use in an internal combustion engine is imperative. A good boiler stoker will often increase the capacity of a boiler 50 per cent. Mechanically operating a gas producer increases its capacity from 100 to 200 per cent.

7 A gas of uniform thermal value is the first essential of economical combustion either in a gas furnace or a gas engine. To obtain such a gas from bituminous coal it is imperative that the producer be operated both uniformly and continuously.

8 We do not hesitate to spend large amounts in the endeavor to increase our engine efficiency a few per cent. Meanwhile we should not overlook the *greater* possibilities for economy which lie in the mechanically operated large gas producer for low grade fuels.

9 Our more expensive fuels, the kind that are now being successfully gasified, do not require much agitation or attention, especially in small sized producers; but my experience with hand operated and mechanically operated producers, using or attempting to use the cheaper fuels, has inclined me strongly to the belief that complete

mechanical operation must be developed and worked out satisfactorily in this country before we can say that the gas producer offers an entirely adequate solution for the rational utilization of our low grade fuels.

MR. L. R. POMEROY In the northwestern section of this country lignite coal is located in a district where the water is very bad indeed for boilers. As a matter of fact there are certain water tanks where if an engine should take water from them it would go "dead" in a forty-mile run. The consequence is that locomotives on that particular division do not pull more than one-half of the rating or of the tonnage that they do on other divisions where the water is more favorable. The lignite coal in this particular section is entirely out of question for fuel under stationary or locomotive boilers.

2 The St. Louis United States Government tests, which with lignite coal of about 36 per cent moisture were able to show a consumption of little over three pounds of coal per horse power hour is very interesting in this connection from the standpoint of the possibility of generating gas power and possible electrical operation; and it occurred to the speaker that, in other districts where the water is of like character and difficult to get satisfactory results, it has put a premium on the further utilization of the power of low grade coal through gasification.

MR. J. R. BIBBINS This subject presents a number of extremely interesting phases, not only in steam, but in gas power application. I wish to refer particularly to the low grade fuel produced in enormous quantities at the various anthracite collieries that appears to be largely unmarketable.

2 Low grade bituminous coal, such as the poorer lignites and and mine refuse, presents a problem quite distinct from that of anthracite refuse. The Jahns producer has been mentioned in this connection, from which excellent results have been obtained in Germany, some of the coals running as high as 70 per cent non-combustible. This, on its face, would almost indicate a solution of the bituminous producer problem, but we learn that all fuels possessing the obnoxious coking qualities (such as tend to form a solid mass in the producer and impede the progress of the blast gases) are unfit for use in this producer. This disqualification puts the damper on our enthusiasm for bituminous producer work, which the average European finds it difficult to understand in regard to American practice. The relative character of coals appears to be the point at issue rather than the

type of producer, and in the last analysis the most successful producer will be that adapted to the use of the cheapest form of bituminous coal, such as Pittsburg or Illinois slack.

3 With this digression, we return to the subject of anthracite, and it may be of interest to the Society to know of some results that have been obtained in a practical producer test[1] having for its object the determination of the operating qualities surrounding the use of these fuels. It may have some bearing upon the subject to say that our attitude was consistently negative, and the tests were made purely in the interest of a large coal operator who desired to market his low grade product in the form of electricity conveyed by long-distance transmission to centers of consumption, rather than in the form of small sized coal for which the market is neither stable nor lucrative. Part of the product, culm, cannot be marketed at all, and it is constantly accumulating at an embarrassing rate.

FIG. 1 SAMPLES OF BUCKWHEAT, RICE AND BARLEY; RICE AND BARLEY; AND CULM, RESPECTIVELY

4 The samples available for test are shown in Fig. 1 and comprise mixtures of No. 1, 2 and 3 buckwheat in the proportions regularly delivered by the breaker, it being the idea to expend no effort whatever in attempting accurate sizing. At this breaker, No. 1 buckwheat passes *through* a nine-sixteenths inch screen, and No. 3 or barley *over* a three-thirty-seconds inch screen, the remainder being culm. Of these sizes, two series were tested; the first, freshly mined coal, and the second, crushed coal from the surface of an old "slate" pile containing 200 000 tons that had weathered for 20 years, but with apparently very little deterioration. The latter contained some "bone," but little slate, and on the present market would probably pass as a fair grade of coal. Practically the same results were obtained from both series of samples. The smaller sizes analyzed as follows:

[1] Made in the producer gas testing department of the Westinghouse Machine Company, East Pittsburg, Pa.

PROXIMATE ANALYSES

	Rice and barley. Per cent	Culm. Per cent
Moisture	8.2	3.43
Volatile matter	5.73	4.87
Fixed carbon	62.72	61.07
Ash	23.35	30.63
	100.00	100.00
British thermal units per pound	10 918	6748
Through one-sixteenth inch screen, per cent	9.16	84.0
Sulphur		2.34

5 These mixtures were tested in a 500 h.p. standard pressure producer, operated in connection with the gas engine testing plant. No alterations were made in the plant to accommodate the smaller size fuel, and the same producer men were employed, although none of them had had previous experience with small low grade fuel.

6 The tests extended over a period of several weeks' duration. As buckwheat was standard producer fuel, and had already been used successfully in large quantities, no attempt was made to screen out this size. The buckwheat mixture, therefore, proved quite satisfactory. No bad clinker developed, and, with ordinary care, the fuel bed could be kept in good condition and normal gas generated.

7 It was, however, found desirable to reduce the usual depth of fuel bed about 25 per cent, to lower the resistance to the blast, but, other than a slightly higher blast pressure, results were not appreciably different from those obtained with the coarser fuel. The producer was handled carefully, but no more so than in the case of normal operation.

8 The accompanying log, Fig. 2, shows the results obtained upon the eighth day of this continuous run on rice and barley. Note that this log covers a continuous period of seven hours, and that the uniformity of the results obtained is the best indication of their accuracy. Short time tests are always open to criticism by reason of the fact that the results are so much more subject to internal influences, especially variations in the methods of charging coal. Note that the *total* heat value only is shown on this log.

9 A day's trial, with a mixture of culm, rice and barley, soon indicates the inadvisability of using straight culm, which was practically dust and showed a natural tendency to pack the fuel bed more than ordinary blast pressures could overcome, and as it was apparent that

successful operation for any length of time would be problematical, involving more care than the low market value of the fuel would warrant, this fuel was abandoned.

10 During the succeeding days of the test, the producer was run on a rice and barley mixture, by some new men who were furnished with no special instructions as to the method of handling the producer. Naturally the results were not as good, Nevertheless, the full engine

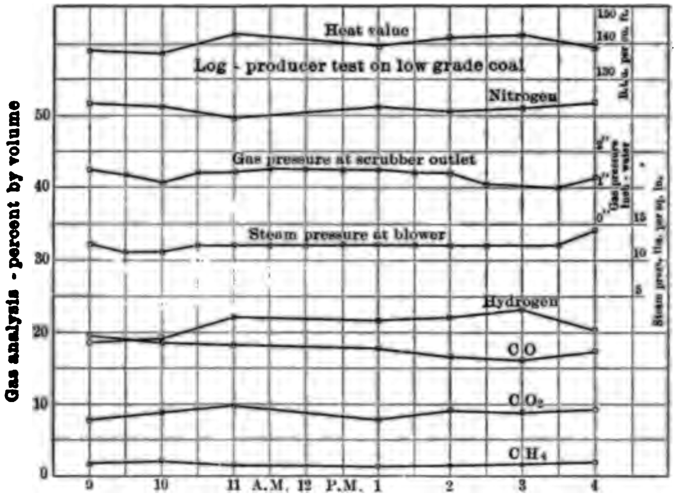

FIG. 2 LOG OF PRODUCER TEST, LOW GRADE ANTHRACITE

load was maintained as usual. The following table gives a fair example of the gas made by these "green" operators, as compared with that possible with careful operation, as shown by the log.

GAS ANALYSES

	Fair gas Per cent	Good gas Per cent
Carbon dioxid	9.4	9.6
Carbon monoxid	14.6	17.8
Methane	1.2	1.2
Hydrogen	16.9	21.9
Nitrogen	57.9	49.5
Total British thermal units per cubic foot	115.5	142.5
Effective British thermal units per cubic foot	105.0	127.0

11 A large variation in producer output with this fuel need have no effect upon the heat value of the gas, providing the blast is con-

trolled automatically. The accompanying log, Fig. 3, shows the results obtained during two hours of a run with this point in view. During this period coal was charged only once; the heat value averaged 131 B.t.u. total per cubic foot, varying only 3.75 per cent from the mean. With the instantaneous changes in output shown by the lower curve and the practical uniformity of the gas, the point is clearly proved.

CONCLUSIONS

12 With careful operation, a buckwheat, rice and barley mixture will produce a gas quite equal in heat value and uniformity to standard gas made from pea anthracite. With the rice and barley mix-

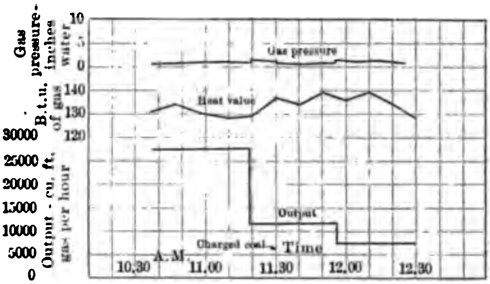

FIG. 3 LOG OF THE TEST OF AUTOMATIC PRESSURE REGULATOR OPERATING ON 500 H.P. PRODUCER

ture alone, a gas as low as 100 B.t.u. may be expected at times, and should be provided for in the design of the gas power equipment. Gas engine ratings should manifestly be based upon such cylinder sizes as will be sufficient to insure full load with the poorest gas allowable. Undoubtedly present standard producer and engine ratings might be adhered to with careful and intelligent operation. This is quite true with the buckwheat mixture, but with finer mixtures conservative engineering dictates slightly lower ratings, especially in mining regions where low priced labor must be reckoned with. This departure from present standards, however, is a matter for individual consideration and not necessarily broadly applicable.

13 Now the question arises: Whether commensurate results may be obtained from this low grade anthracite burned under steam boilers, and if so, will the gas engine proposition be outclassed in the financial balance sheet? My observations at the collieries where this fuel is produced leads to a negative conclusion, as far as comparative

operating costs are concerned. At this plant a mixture of rice with a little barley is used on a flat herringbone grate with three-sixteenths inch openings, with a grate surface ratio of one-thirty-fifth, the average firing rate is only 13.8 lb. per square foot of grate surface per hour and with induced draft of one to two inches in the flues. One fireman cannot handle conveniently more than 450 h.p. capacity, or about one gross ton per hour. A test with rice on a 300 h.p. horizontal return tube boiler gave an evaporation of 6.23 lb. per pound of dry coal and about 75 per cent rating. This is equivalent to an average evaporation of about 5.75 lb. as actually fired.

14 In general terms, the subject seems to present the following aspects:

- *a* Hand firing is a practical necessity, involving at least three times the labor required for producers equipped with coal handling machinery;
- *b* Boiler efficiency decreases rapidly with sizes below one-fourth inch, probably averaging not over 50 per cent with a rice and barley mixture;
- *c* Boiler capacity is similarly affected, affording little or no forcing capacity;
- *d* The effect of ash in large percentages has a far more serious effect on boiler than on producer efficiency and capacity. Mr. W. L. Abbott's valuable experimental work with bituminous screenings, illustrates this in a striking manner. He has shown, however, that within reasonable limits, low grade *bituminous* coal can be used successfully and stoker fired. A recent test at full boiler rating on an 800 horse power double fired boiler equipped with Roney stokers has also shown good results with buckwheat anthracite containing as much as 23 per cent ash; a firing rate of 20 lb. per square foot of grate surface per hour; a boiler efficiency of 75.6 per cent, and an equivalent evaporation of 8.77 lb. per pound of dry coal.

15 Thus a certain part of the low grade fuel fields is available for steam purposes with mechanical stoking, but it seems conservative to limit the boiler to No. 1 buckwheat size for the most effective results. Below this size the producer evidently finds a special and fortunate application.

16 Finally, a word as to sizing. Mr. Coxe (Report of Pennsylvania Coal Commission) has shown that a most confusing state of affairs exists in this regard. At the time of this investigation by the

various operators there were in use 12 different specifications for pea, 15 for buckwheat, 16 for rice, 5 for barley and 16 for culm, the latter varying from a one-sixteenth inch round to a three-eighths inch square mesh. Both wire screen and punched plate were in use with square, round, oblong and slotted apertures, these varying from 30 to 100 per cent in diameter for supposedly the same size coal. Obviously, the only remedy for this muddle is a rigid standardization, and until such mutual action is taken, the customer must familiarize himself with local standards of the various collieries.

17 In regard to the trend of the preceding discussion on the general use of low grade fuels, I believe Professor Lucke's remarks are not representative of present conditions, or at least do not carry the proper inference. The relative "expensiveness" of two power propositions, involves operating, as well as fixed charges. Admittedly, the gas power equipment is at present more expensive in first cost, but in the great majority of cases (excepting only those of exceedingly low fuel cost and loading factor), it quickly makes up for the deficiency by reducing the operating costs.

18 I cannot agree with Professor Lucke that the equipment labor cost is much higher in the gas generating than in the steam generating plant, as I have pointed out above in the case of low grade anthracite. The specific instance he cites, in which the producer labor was abnormally high, does not apply, in the least, to a well managed plant. When it is considered that in a producer plant, only one-half, if not a smaller percentage, of the total fuel tonnage of an equivalent steam plant has to be handled, and this practically by gravity, the injustice is apparent; and only in the case of a comparatively large installation, where fuel is handled entirely by good mechanical stokers, will a steam plant be able to rival its competitor in economy of labor. With high grade, double acting gas engines, in which lubrication is accomplished entirely by automatic means, where is the opportunity for the abnormal expense charged against the gas plant? Simply because some small gas installation of any given type happens to require the same number of men that would suffice for a plant perhaps twice as large, it is illogical to inveigh against the gas proposition as a whole. In the early stages of gas power development, which naturally involved small sizes of apparatus, criticism of this kind was frequent, but with the establishment of larger plants, the opportunity for normal economy in labor arose. There is, of course, considerable difference between the operation of a simple anthracite plant, involving no auxiliaries, and a bituminous plant requiring either periodical fuel bed renewal or

independent purifying auxiliaries. Bituminous practice is, however, rapidly crystallizing into more simplified operation, and even at present bears out the above contention.

19 Furthermore, I maintain that an adequately designed producer can show far better results as to continuity of operation than the average boiler plant. A fundamental necessity, of course, is a water-sealed type of producer, permitting gradual and uniform disintegration of fuel to ash without necessitating the renewal of fires at week-ends. An instance will suffice, a 500 horse power producer installation at Jersey City, using small anthracite. I am informed at first hand by the engineer in chief that one of the producers, installed in 1898, was in operation 21 to 24 hours per day for a period of six years and ten months without the fires ever having been drawn. And only then was a shut down necessary because the coal feeding bell had rusted off at its point of suspension and fallen into the fuel bed from which it could not be recovered without drawing the fires. Incidentally, the producer lining was found to be practically intact, and as soon as the bell was replaced, the producer was put back into service. This clearly indicated the possibilities of the water-sealed type of producer.

20 Nor has the gas engine shown inferior results. A four months' operating record from a Kansas cement mill shows the following results from engines of standard Westinghouse construction:

Type of engine	Number samples	Size brake horse power	Total run per cent of total time	Engine repairs, per cent of time
Four months run:				
Horizontal double acting..........	3	500	95.6	0.63
Two months run:				
Vertical, single acting.............	13	125 to 300	97.95	1.13

21 When it is considered that up to January, 1907, one manufacturer alone had equipped 69 producer plants, located in all parts of the world, varying in size up to 3000 horse power, many of them having been in operation from five to seven years, it does not seem reasonable to term the gas power system as commercially unfeasible.

Mr. W. H. Blauvelt When the American engineer goes to Germany to study these processes for the utilization of low grade fuels he must remember that in this country the chemical manufactures are by no means in the advanced state that they are in Germany, for the working up of the by-products. We have here almost no chemical manufacturing of the more refined products of tar, such as the various colors and dyes, or the many coal tar medicines. We may almost say that our manufacture of tar products hardly goes beyond the first crude distillation of the tar, with the production of pitch and creosote oil. During the last few years a very important percentage of the total tar production of the country has been burned as fuel, on account of there being no other demand for it. I recently visited a manufacturing works which was burning daily from 20 000 to 30 000 gallons of tar under its boilers, on account of there being no market. Now we hope that these conditions will improve, and some of us are doing a good deal of hard work with that object in view, but they do exist at present.

2 Compared with the continent of Europe, the market for ammonia in this country is very small, and the great European demand for sulphate of ammonia for fertilizers is comparatively unknown here. These conditions must be kept carefully before us in our study of methods for the utilization of low grade fuels. Moreover, we must remember that tar made in the gas producer is not of the same quality as that produced by direct distillation, as in the gas works. Producer tar is the product of partial combustion, and is essentially different in composition, containing more of the paraffines, for example, and less of the valuable creosotes, anthracenes, etc. The pitch has not the same cementing qualities, and must be considered as a comparatively inferior article to good coal tar pitch. It is more like the pitch produced in the Scotch blast furnaces, for instance.

3 Dr. Lucke referred to the relative cost of gasifying coal in producers versus direct firing for boilers. I wish to second Mr. Bibbins' rejoinder that the case does not stand so strongly against the gas producer, especially if we accept as a fact Mr. Junge's presentation that gas producers can be adapted to the very low grades of fuel which could be procured for a lower cost than fuels suitable for direct firing under the boiler. I agree with Mr. Bibbins that the cost of operating producers and handling coal for them can be very greatly improved over the figures ordinarily obtained in producer plants. I believe that a large producer plant of proper design can be operated with lower labor cost than a direct fired boiler plant. I think it has been definitely shown that the superior economy in boiler firing with gas more than makes up for the loss of efficiency in the producer in the gasification of the coal.

4 In connection with the utilization of low grade fuels, I wish to call the attention of the Society to the commercial beginning of the

briquetting industry in this country. The United States Government Testing Plant at St. Louis, and several private briquetting installations have made some definite steps forward in this industry. There have been some especially interesting demonstrations of the usefulness of briquetting in making valuable the great deposits of lignites in the West. I have seen these lignites briquetted at St. Louis which did admirable work in steam production, and which would stand exposure to the elements for a year without injury, while the original lignite would crumble to a fine powder within a fortnight. Briquettes are also being made commercially from the small sizes of anthracite at Scranton. The entire product, I understand, is now being sold to railroads for locomotive use. There are other installations in Detroit, Kansas City, and on the Pacific coast, each briquetting the local fuel, and preparing them to meet the local demands. The process of briquetting is in itself a simple one, although each fuel has certain conditions which must be very accurately met and maintained, in order to produce good results. I believe we may expect to see by the development of this industry a very important utilization of many of the fuels now nearly useless.

MR. R. KLEIN[1] Mr. Junge advocates to the American Nation, rather than to the responsible and enterprising individual, to install the fuel saving gas power plants, on the assumption that the fuel cost of a power plant is by far the largest single item of its operating expense. This is the case in Germany where a gas power plant can be built for $100 and even less per rated kilowatt; a steam plant for $70; and where a good grade of coal of 12 000 British thermal units costs $1.90 per ton at the mine and lignites of about 7500 British thermal units cost $1.25. In places distant from the mine, these prices increase rapidly on account of the high freight charges and, as a fair average, we can figure that the coal first mentioned costs $4 a ton and the other one $3. In this country, where the conditions are entirely different, it would not be economical to put in a gas power plant whose character of operation would be such as to render its installation advisable in Germany. We will find that under American conditions, not the fuel cost, but the fixed charges on the installation play the most prominent part in the operating expenses of a power plant. This is especially true in the regions of the low grade fuels. A comparison between a medium size complete gas power plant, equipped with producers for bituminous coal, and horizontal

[1]Consulting Engineer. New York.

double acting gas engines and a modern steam plant equipped with steam turbines, etc., both able to carry a peak load of 3000 kilowatts, will prove this.

2 Another basis than that of a peak load in this comparison does not seem fair, as the stations must have sufficient power in them when called upon. In cases of less load we have to divide the work among the engines to the greatest advantage in each station. Prof. Charles E. Lucke points this out in his interesting paper on power cost read before the American Electrochemical Society in February, 1907.

3 For further comparison, the cost at which the unit of power, one kilowatt-hour, can be produced shall be the basis on which will be decided what kind of plant will be the most economical. The cost per kilowatt-hour equals the operating expenses of the plant, divided by the output ranging over a whole year.

4 It should be understood that these figures necessarily cannot be universally correct, as they do not take local conditions into consideration with the exception of the price of coal and the load factor. However, they are accurate enough to be adopted as a general basis for this country.

5 The cost of a complete gas power plant, including building and foundations, coal handling apparatus, crane, power house cables, conduits and switchboard is per kilowatt of peak load $130. For a similar turbine plant this figure would be $70. Assuming the peak load 50 per cent above normal rating of station the prices per rated kilowatt would be respectively $195 and $105.

6 Where natural or blast furnace gas is available, the cost of the gas power plant per kilowatt drops, respectively, to $135 and $143, on account of the omission of a producer plant. In the cost of the blast furnace gas plant, $8 per rated kilowatt is included for the gas cleaning plant. As the application of a plant running on blast furnace gas depends too much on local conditions, we only include the natural gas plant in this comparison. The appraising of the blast furnace gas varies greatly in different plants, as is pointed out clearly by Mr. H. Freyn, in his valuable paper on "Blast Furnace Gas Power Plants," presented before the Western Society of Engineers, December 1905.

7 Although on account of the greater stresses on the material of gas engines, the depreciation on the same should be assumed higher than with the steam turbines, we rate the fixed charges for both plants alike, that is, 10 per cent on buildings and 15 per cent on machinery.

8 In the fuel consumption per kilowatt-hour we assume that a

gas power plant averages 1.75 pounds and a steam plant 3.5 pounds of bituminous coal of 14 500 British thermal units.

9 The figure for the gas engine plant cannot be very much improved as the producers cannot be made of larger capacity than are used in the 2000 kilowatt station and as the higher mechanical efficiency of larger engine units is offset by lower thermal efficiency, on account of increase in ratio of cylinder volume to cylinder cooling surface, which does not permit as high a compression as with smaller engines. For steam engine plants of larger sizes the figure of 3.5 pounds of coal per kilowatt-hour can be decreased considerably, also the fixed charges when units of 5000 to 10 000 kilowatts are installed. The large stations in New York City are producing their power over 30 per cent cheaper than this estimate gives.

10 For fair comparison an allowance is made for coals of other heating values. Still there may be a difference in boiler efficiency on account of percentage of ashes in the coal, which may range from 70 per cent to 60 per cent with ashes ranging from 5 per cent to 30 per cent.

11 With poor grades of coal, provision should be made for larger grate areas than is customary with the higher grades. We do not account for this difference in efficiency, as most modern gas producers show a difference along the same lines.

12 Efficiency for producers burning cokes or anthracite is 80 per cent, bituminous coal and briquettes with tar combustion 75 per cent, bituminous coal without tar combustion 65 per cent.

13 The efficiency of a producer drops with the load in a similar manner as that of a boiler; at three-quarter load the efficiency is 96 per cent of that at full load; at one-half load it is 92 per cent and at one-quarter load it is 75 per cent.

14 In the following table it is assumed that a gas engine plant consumes 18 cubic feet of natural gas of 1000 B. t. u. per kilowatt against a consumption of 50 cubic feet of a steam plant. The rated capacity of the plant is 2000 kilowatts.

15 The two most important variable items deciding the choice of the type of plant are the load factor and the price of fuel, or rather the product of the two, which we will call the fuel factor. Assuming 100 per cent load factor as unity in this product and $1 per ton of bituminous coal of 14 500 British thermal units per pound also as unity, the fuel factor of a plant running under these conditions is unity as in the first example for coal; in the second case it is 2, in the third case 1; in the first and third example it is 2.95 for natural gas.

16 Fuels of less heating value are appraised accordingly. If coal

of 10 000 British thermal units costs 90 cents and the load factor of the station is 30 per cent, the fuel factor is:

$$\frac{14\ 500}{10\ 000} \times 0.90 \times 0.3 = 0.4$$

TABLE 1

COMPARATIVE OPERATING ECONOMY FOR GAS AND STEAM POWER STATIONS

RATED CAPACITY 2000 KW.

Type of Station	GAS POWER		STEAM POWER	
Fuel	Coal	Nat. Gas	Coal	Nat. Gas
Price of coal delivered on the grate $1 per ton, gas 10 cents per 1000 cu. ft. unit load factor.				
Fuel factor	1	2.95	1	2.95
Fixed charges on buildings 10 per cent	8 000	5 000	4 600	4 600
Fixed charges on machinery 15 per cent	46 500	33 000	24 600	24 600
Office and engine room labor	6 800	6 800	6 800	6 800
Repairs	6 900	2 600	4 300	4 300
Oil and waste	5 600	5 600	3 800	3 800
Cost of fuel	15 400	32 000	30 800	89 000
Total operating cost	89 500	85 000	74 900	133 100
Cost per kilowatt-hour	0.51c.	0.485c.	0.43c.	0.76c.
If the price of the coal were $2, and of the gas 6.8 cents the figures would be:				
Fuel factor	2	2	2	2
Total operating cost	104 900	75 000	105 700	105 700
Cost per kilowatt-hour	0.60	0.43c.	0.605c.	0.605c.
For coal $2, gas 20 cents they would be at one-half load factor:				
Fuel factor	1	2.95	1	2.95
Total operating cost	same as in first example			
Cost per kilowatt hour	1.02c.	0.97c.	0.86c.	1.52c.

[1]As price of coal is figured delivered on the grate, boiler room labor is omitted.

[2]A little deduction in expenditures could be made for repairs and oil and waste in this last case, but would change the comparison only to a small extent.

17 Natural gas can be appraised similarly. Gas of 6.8 cents per 1000 cubic feet of 1000 British thermal units and load factor of 100 per cent gives a fuel factor of:

$$\frac{14\ 500 \times 2000}{1000 \times 1000} \times 0.068 \times 1 = 2.0,$$

as assumed in the second example.

18 The figures show that in the natural gas regions, the gas plant wins out as long as the fuel factor is higher than 0.45, corresponding to a price of gas of 1.5 cents and unit load factor or three cents and one-half load factor or six cents and one-quarter load factor, etc.; that is in most practical cases except when the gas is idle at the well. They also show when a steam plant using coal should be installed in regions where natural gas is available.

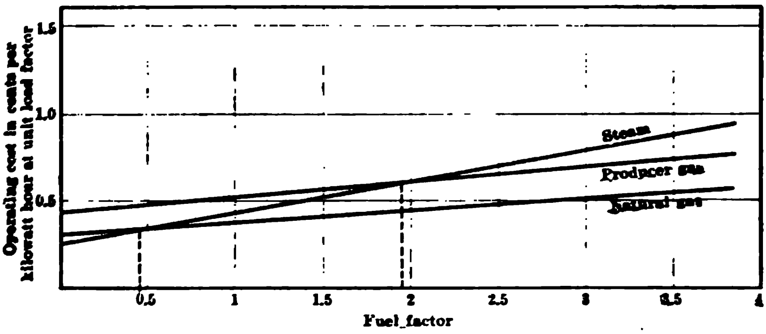

FIG. 1

SHOWING THE COST PER KILOWATT-HOUR AT UNIT LOAD FACTOR

For any other load factor the amount given should be divided by the same. EXAMPLE: 1.5 fuel factor and one-half load factor gives 0.56 : ½ = 1.12 c. cost per kw-hr.

19 We see further that plants using coal with a fuel factor of 2 and over call for application of gas engines, while with a smaller factor a steam plant is necessary to get the most economical results. On this basis an engineer may advocate a gas plant and a steam plant next door to each other, basing his advice solely upon the fuel factor. The coal being of the same price it is the load factor that decides between the two types of plants. For instance, in a case of coal at $3 and the load factor of the station 90 per cent, or a fuel factor of 2.7, a gas engine plant would be advisable; in the same locality in a factory running full load during ten hours of the day, hence having the fuel factor of 1.25, a steam plant would be most economical.

20 In the regions of the low grade coals of this country where the bituminous slack coal may be bought for 40 cents a ton at the mine

or for $1 at points over 100 miles distant from it, an expensive gas plant would not be advisable, even if provisions were made for by-product recovery. Mr. Junge gives us an excellent description of this progress, but tar and its oils which he seems to consider by far the most important of these by-products are hardly marketable in this country; in fact most of the gas plants burn their tar under boilers because they cannot sell it to advantage.

21 In these regions the fuel factor cannot be larger than 2 unless the coal delivered on the grate costs at least $2 per ton, which is seldom the case, and then the fuel factor would be 2 only for plants running full load day and night. In view of these figures it would be decidedly a mistake to install gas power plants with by-product recovery in any of the regions of the low grade coals and the charge of Mr. Junge to the American people of lack in technical training and industrial fore-thought on account of not installing this kind of plant, should at least be minimized.

22 It will not do in this country to start a briquetting business with an output of 4.2 tons a day to receive $3 per ton for briquettes instead of 55 cents per ton for coal dust. The cost and difficulty of manufacturing briquettes puts them behind in competition with coal; this is also the case with the large deposits of peat which are found in this country.

23 Mr. Junge concludes by saying that the rational utilization of coals requires the adoption of gas producers and gas driven central stations. This may all be true, but we have not only to consider the utilization of coals but also that of capital and labor. Capital in the cost of the plant, labor in the manufacture of the machinery. The recent panic shows clearly that capital invested too lavishly in new enterprises is more detrimental to a country than the consumption of somewhat greater quantities of fuel where this is abundant.

24 The natural resources of this country are so abundant that even while America consumes 9000 pounds of coal and 700 pounds of iron per capita per year against 7000 pounds of coal and 320 pounds of iron for Germany, the corresponding saving in capital invested and labor cost is such as to place the American to a greater financial advantage over his German competitor. Besides, the American should not forget that he pays yearly a fairly high interest on the mortgage on his business in the shape of a dividend to the European shareholders of American stocks.

Mr. R. E. Mathot The very elaborate paper of Mr. Junge deals almost entirely with theoretical suggestions and general considerations regarding the efficiency of gas motive power. Perhaps it may not be out of place to describe here a little practical device, the use of which may lead to economy in the operation of gas plants by securing a method of watching the nature of combustion in the gas engine's cylinder.

2 If combustion is complete, owing to perfect mixture, which affords high efficiency, the exhaust gases should not contain any unburned gas such as CO. The presence of this gas in very small proportions in the exhaust can be detected by a simple appliance. A small glass flask, about two inches in diameter and four inches high, closed with a cork, through which pass two vertical tubes, is used for collecting some of the exhaust gas. One of the tubes is connected to the exhaust pipe of the engine, while the end is plunged in mercury about one inch deep in the flask. As soon as the connection between the exhaust pipe and the flask is established, some exhaust gas will be blown into the flask at each stroke, and the mercury, operating as a check-valve, will prevent it from being withdrawn. The air contained in the flask, and afterward the exhaust gas, will be expelled through the second pipe open to atmosphere and ending inside, at the top of the flask.

3 To detect CO, which is contained in the exhaust gas continuously rushing through the flask, a small piece of white blotting paper is hung in the flask, the paper being previously prepared by dipping five or six times in a solution of double chlorid of palladium and sodium of such concentration as to give a dark brown color, and drying after each immersion.

4 If there is more than 1 per cent of CO in the exhaust gases, the paper will, in two or three minutes, lose its bright brown color and become gray. This shows insufficient air in the mixture for combustion, which can be corrected at the mixing valve.

5 I have been interested in the competition between the gas and steam engine, but I do not agree with those who affirm that the gas plant will drive the steam engine from the field. On the contrary, I am of the opinion that both kinds of motive power will grow side by side and even stimulate each other to greater improvements.

6 In a series of articles contributed to the Engineering Magazine at the beginning of this year, I described several installations of steam and gas plants to meet different conditions. Gas, steam, liquid fuel or water, as sources of motive power, each possesses qualities better adapted to some special purpose than the others.

7 The low figure attainable in a suction gas plant of 0.7 lb. of anthracite per brake horse power hour, has been met by the correspondingly low figure of 1.35 lb. of bituminous coal in a steam plant.

Such steam plants are not, of course, common, and the figure given refers to a type of semi-portable engine, made by two well known German firms, H. Lanz in Manheim and R. Wolf in Magdebourg, with a self-contained boiler, the engine being mounted upon the boiler which supports its chimney stack.

8 The boiler is of the horizontal type with internal corrugated furnace from which extends a set of fire-tubes. The furnace and tubes are a removable system. The single or double superheater is placed immediately behind these tubes, in the fire-box, so that superheating is obtained by the heat of the gases before passing to the chimney. The engines are horizontal, of the piston-valve slide type, and are made single, compound or triple expansion with single, double or triple superheating ranging from 300 deg. to 350 deg. cent.

9 The very low consumption is mainly due to the high efficiency of the boiler and superheating arrangement, although the heating surface is small; to the high working pressure; to the absence of steam pipes; the high speed of the engines and high grade workmanship.

10 The following figures are abstracts of a test that has been recently made on one of these semi-portable engines.

Brake horse power	150
Mechanical efficiency	92 per cent
Initial steam pressure	180 lb. sq. in.
Steam vaporized per pound coal	8.5
Gross consumption bituminous coal per brake horse power hour	1.22 lb.
Heat values of said coal	14 500 B. t. u.
Ash	6.2 per cent.

11 Another test on a 300 h. p. engine has shown even better results. Full data of the experiments and the illustration of these engines have been published in Power.

12 It is proposed by Mr. Wolf to do still better and he is building a 500 h. p. triple expansion, semi-portable engine, with triple superheating; that is, the steam is separately superheated before entering each cylinder. He expects the following results:

Working horse power	500
Initial steam pressure	215 lb.
Heating surface	815 sq. ft.
Gross coal consumption per brake horse power hour	0.99 lb.
Steam per brake horse power hour	8.15 lb.

Dr. J. A. Holmes In discussing this admirable and interesting paper, it is perhaps appropriate that I should allude to points in it bearing directly upon the fuel investigations undertaken by the U. S.

Geological Survey at the St. Louis Exposition, and which have been more or less continued, in part, under the supervision of the representatives of this Society. I desire particularly to call your attention to that phase of the investigation dealing with waste that has taken place in mining, and in the utilization of both high grade and low grade fuels in this country.

2 The investigations that have been conducted at St. Louis, at Norfolk and at Denver, during the past three years, had for their cardinal purpose the comparison of one character of fuel with another, determining their heating values and how each might be used most efficiently. It was hoped, and in part only was that hope realized, that these engineering investigations would give us results even more valuable than they were; but the equipment which we were compelled to use in the beginning was selected because it was available under the provisions of the appropriation by Congress; and because it represented the ordinary power plant in use in the United States.

3 Our recent investigations of the waste in coal mining indicate that often 30 to 40 per cent of the coal is still being left underground as pillars; and that in many cases from one-sixth to more than one-third of a given bed of coal is being left underground because of its high content of ash or sulphur. In certain mines the amount of coal left unmined, exceeded 75 per cent of the total and the average result is that, taking the country as a whole, at least 50 per cent of the possible coal supply is being left under the ground and unrecoverable. This means a loss of 400 000 000 tons of coal per annum which at the low price of $6.50 per ton is a loss of $200 000 000 each year.

4 This 50 per cent of the total possible coal product referred to as being left underground includes, besides the supporting pillars, also the low grade parts of the coal beds and the adjacent overlying bed of coal damaged in mining the lower beds. This, like the loss of the 90 to 95 per cent of the heat units in converting the coal into work, will probably never be entirely preventable, but every decided advance along either of these lines is a distinct gain and contributes both to the present and the future welfare of the nation. The country's fuel bill, taking the fuel in the furnace, now aggregates the enormous sum of more than $1 500 000 000. The keeping down of this bill, and lessening the $200 000 000 waste in mining are two of the problems the Geological Survey is trying to aid in solving.

5 Now we have found that the percentages vary all the way from 20 to 50 per cent ash in the so called low grade coals. I recall one case in particular in which out of a possible 25 foot vein of coal only

4 ft. were taken out because of indifference in mining, and the rest left underground and practically destroyed. The thoughtlessness with which coal miners have gone to work mining the lower beds and allowing cave-ins to follow, has had the result of leaving the coal in the higher beds unmined and practically lost because of the caving-in of the adjacent strata. In West Virginia and in Ohio, and in various other places, the cost of mining has been greatly increased, entirely out of proportion to the amount of coal that has been mined. If with greater cost there is a corresponding increase in efficiency and less waste in mining, the country is benefited to that extent.

6 I desire to call attention to the possibility of utilizing these coals by the location of plants at the mines, thus avoiding the cost of transportation. Consider as a single illustration the Pennsylvania Railroad, which uses 40 000 tons of coal every day in its own locomotives. If, as is now being suggested, all of that power for operating these trains be generated in power plants located at or near the mines from low grade fuels now not utilized at all, we shall see an enormous gain in the direction of a solution of our fuel problems; and our problem of transportation would be vastly lessened. On the Pennsylvania Railroad 800 cars now used each day for hauling coal for the use of its locomotives might be used for transporting ordinary articles of commerce. Consider for a moment what the application of this same plan would mean to the 100 000 000 tons to coal now annually consumed in our locomotives.

7 Very few persons realize that so rapidly is the fuel industry developing that during each succeeding decade for the past 85 years the amount of coal mined and used in the United States has equaled that of all the preceding decades. Thus the amount of coal mined between 1895 and 1905 was nearly equal to that mined and used during the preceding 75 years. Now, there has not been a corresponding increase in efficiency, nor has there been so marked a gain in the utilization of the low grade materials. What we are doing at the present time is skimming the surface, using the high grade coals and leaving the deeper coals. Therefore, we are approaching a condition where our coal cost will be greatly increased and the amount of available high grade coal very much diminished. No one can now say when that time will come, but we should see to it that our coal supply will last longer than that of any other country. We must awaken to the fact that our high grade coals are passing so rapidly that coal lands used for supplying coke and for other special purposes in Maryland and in West Virginia cannot be purchased in many sections for less than $1500 to $4000 an acre. These high grade coking

coals should be reserved for the manufacture of iron and steel and other metallurgical purposes. The spirit of wastefulness is abroad in the land, developed from the luxurious wealth of the country, until one can hardly realize the extent of it. Recently a party of mining engineers visiting one of the great lead and zinc mining camps of the country found that fully 50 per cent of the possible supply is left unmined or wasted in processes of treatment. The same thing applies equally well and just as truly to other mineral resources of the country.

8 I may say, in conclusion, that while these investigations have been in part under the supervision of this and the allied engineering societies, the President of the United States has, in his message to Congress, recommended the establishment by the Government of a special bureau for mining and engineering investigation, in which the work initiated at St. Louis may be placed upon a higher plane as to equipment and facilities for investigations. It is proposed, furthermore, that this new bureau shall be under the Department of the Interior and working in coöperation with the Geological Survey, and shall be even more largely than heretofore under the supervision of the National Advisory Board made up of representatives of national engineering societies and other allied bodies, who, together with those chiefs of government bureaus who have to do with actual construction work would give advice as to the wise direction for the energies of the new bureau and its larger work.

Mr. H. H. Suplee In regard to the performance of the Wolf engine, of which Mr. Mathot spoke, I think there is no doubt about its very high efficiency. I had occasion some time ago to examine some data and results of tests on some of these engines made by Professor Gutermuth, and the performance corresponded very closely to the figures given by Mr. Mathot.

2 The high efficiency in this case, I think, is largely due to the elimination of transmission losses. It was shown at the Chattanooga meeting, and also by the experiments of Dr. Berner in Germany, that superheated steam loses its heat very rapidly. In the Wolf engine, the steam passes first through a coil superheater in the smoke box, where the greatest amount of heat is received, and from thence the steam passes directly to the high pressure cylinder. Then there is a similar reheater between the high and low pressure cylinders, and again a very short connection, and the engine is practically working with steam which corresponds very closely to what Professor Rankine calls "steam gas." Mr. Mathot speaks of steam temperatures cor-

responding to 300 deg. cent., or 572 deg. fahr., and at such temperatures the steam is so far removed from the saturation point as to be practically a gas.

3 Such engines really hold a sort of intermediate place between the steam engine and the gas engine, and should be so considered, and their performance bears out this classification.

4 I think that the results of Mr. Mathot with the Wolf engine are fully confirmatory of those obtained by Professor Gutermuth.

Prof. C. E. Lucke It appears that I did not make myself quite clear in my previous remarks in discussing the question of labor cost in firing.

It was not my intention to give the impression that I believe a gas producer costs more to fire than a boiler when operated with favorable fuel. I do not think so at all. The point I wanted to bring out was that when we attempt to pass from favorable gas producer fuel to unfavorable then the cost of firing increases very rapidly.

No. 1166

DUTY TEST ON GAS POWER PLANT

A REPORT OF A DUTY TEST OF THE GAS POWER PLANT OF THE NORTON CO., WORCESTER, MASS.

BY G. I. ALDEN, WORCESTER, MASS.,

AND J. R. BIBBINS, PITTSBURG, PA.

Members of the Society

The following report summarizes the tests conducted on Monday, Tuesday and Wednesday, June 24, 25 and 26, 1907, at the works of The Norton Company, on a complete producer gas power plant serving the works with light and power. This plant comprises, as its essential features, a 500 horse power Westinghouse horizontal, double acting gas engine with a 300 kilowatt direct connected direct current generator and a bituminous gas generating unit of the intermittent type and corresponding capacity, built by the Power and Mining Machinery Company. The test was purely a service run under the regular operating conditions prevailing at the plant, and with the power equipment in charge of the regular operating force. Load was, however, maintained during the night periods, 6:00 p.m. to 7:00 a.m., in order to shorten the test and eliminate the necessity of correcting for more or less intangible losses.

2 The test was executed conjointly by The Norton Company, under the general direction of Mr. Geo. I. Alden, and by The Westinghouse Machine Company, represented by Messrs. J. R. Bibbins and Daniel Armistead. In consequence of their general interest in the subject, The Power and Mining Machinery Company and the American Steel and Wire Company very kindly furnished skilled observers from their respective engineering staffs to assist in obtaining the required data. A complete schedule of observers is presented in the appendix, and acknowledgment is here tendered these gentlemen for

Presented at the New York Meeting (December 1907) of The American Society of Mechanical Engineers, and forming part of Volume 29 of the Transactions.

[illegible]

[illegible]

Objects of Tests

1. The principal object was to determine:
   a. The heat efficiency of the plant [illegible] and approximately [illegible] coal.

Incidentally, other valuable data were readily available and were accordingly included in the investigation.

   b. Heat efficiency of the gas engine at various loads.
   c. Mechanical efficiency of the gas engine.
   d. Water consumption of the gas engine.
   e. Oil consumption of the gas engine.
   f. Speed regulation.
   g. Thermal heat balance of the complete plant.
   h. Characteristics of gas produced, extent of variations in calorific value and analyses.
   i. In general, the normal operating qualities of the engine and the practicability of the complete producer gas plant for power purposes.

Summary of Results

[illegible]

b.h.p. hr. with 66 degrees fahr. inlet temperature and 47.1 degrees fahr. rise, equivalent to 9.4 gal. per b.h.p. hr. at full rating.

h Average cylinder oil consumption, 1.44 gal. per 24 hours, equivalent to 0.6 gal. per operating day, or 3.2 gal. per operating week.

i Speed regulation, no load to full load, 2.5 per cent above and below mean.

j Average producer efficiency, 74.4 per cent at full load; 73.8 per cent at average test load—both based upon lower or effective heat value of gas.

k Producer gas, average, 114.6 effective B.t.u. during 51-hour test; maximum variation 11.5 per cent above and below mean. Difference between total effective heat values—about $4\frac{2}{3}$ per cent.

4 Summarizing the general results: The test reveals a satisfactory attainment of results. Not only does the engine alone show good operating efficiency, but the plant as a whole, judged by standards of steam plant practice, using perhaps one-third of the coal required for steam power. The absence of interruptions from any cause points to a condition of general reliability sufficient for the character of service rendered. Especially is this the case, inasmuch as the power equipment was not put into prime condition for testing; so that the test represents a certain part of a normal week's run after six months' regular daily operation.

DISCUSSION OF RESULTS

5 Two independent tests were run for the purpose of providing data for segregating the efficiencies of the various parts of the plant; one, a 51-hour continuous load test to determine the coal, water and oil consumption, and the mechanical efficiency; the other, the holder drop series to determine the net heat consumption of the engine at various loads. The methods of conducting both series and observing all quantities are treated in detail in the appendix (and see general plan of test, Fig. 1.)

HOLDER DROP TESTS

6 This series is of particular interest, as it affords a measure of the engine efficiency at fractional loads *without independent adjustment* of detail parts for each load condition; that is, it represents the

efficiency occurring on regular shop load when fluctuating between the usual limits. Under the conditions, the holder drop method was the most convenient and accurate method of determining the efficiency characteristic, and in fact the only one by which the engine efficiency could be definitely segregated.

7 Table 1 summarizes the essential data for plotting Fig. 2. Here

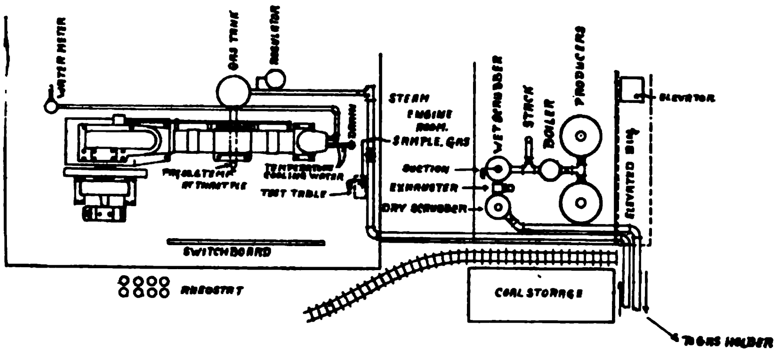

FIG. 1 ARRANGEMENT OF APPARATUS

TABLE NO. 1 HOLDER DROP TESTS

SUMMARY OF RESULTS

TEST NO.	A	B	C	D	E	REMARKS
Duration of run, min	11	8	10	10	10	
Load; per cent eng. rating. No load	No-load	25.4	45.1	70.6	102.2	Circum. holder 110.33 ft.
Brake horse power		127.0	225.5	353.0	511.5	
Kilowatts		84.1	154.3	243.5	352.0	
Speed, revolutions per minute	158.00	156.0	154.0	152.0	150.0	Barom. = 29.26"
Holder drop, ft. per hr.	16.91	24.96	32.22	39.89	51.60	Av. temp. of gas, 71.6 degrees fahr.
Cu. ft. per hr. 30 min. 60 deg.	15 760.00	23 270.00	30 050.00	37 280.00	48 200.00	Av. gas pressure, 2¼ inches water.
Gas consumption rate: Cu. ft. per b.h.p. hr.	(Std. gas.)	183.2	133.2	105.5	94.25	Correction factor—0.9642
Cu. ft. per kw-hr.		276.8	194.8	153.1	137.0	
Heat value of gas: a Effective B.t.u. per cu. ft.	106.4	106.4	106.4	106.4	106.	a Av. of all tests.
B.t.u. per b.h.p. hr.		19 480.00	14 160.00	11 215.00	10 030.00	
B.t.u. per kw-hr		29 430.00	20 720.00	16 280.00	14 560.00	
Thermal efficiency brake, per cent		13.05	17.96	22.68	25.36	
Thermal efficiency (electrical) per cent		11.6	16.46	20.96	23.42	

the graphical method has been used to correlate results. The diagonal line, "cubic feet of gas per hr." represents the relative consumption at various loads, and more accurately than would an arithmetical average by proportion. From this line, the heat consumption line "B.t.u. per hour" is obtained. As it was impossible to take accurate calorimeter readings more rapidly than at 15 minute intervals, and as all of the holder drop tests were taken within a comparatively short period, an average heat value[1] of the gas was used, 106.4 B.t.u. (effective) per cubic foot at 62 degrees fahr. and 30 inches barometer. The curves, "B.t.u. per b.h.p. hr.," and "thermal efficiency," were obtained from the total heat consumption line

TABLE NO. 2 FRACTIONAL LOAD EFFICIENCIES

HOLDER DROP TESTS

NOMINAL LOAD	1/4	1/2	3/4	FULL	OVER-LOAD
Load, brake horse power	125.00	250.00	375.00	500.00	550.0
Gas cons.,[1] cu. ft. per b.h.p. hr.	190.00	127.00	105.6	95.00	92.20
Heat cons.,[1] B.t.u. per b.h.p. hr.	20 210.00	13 510.00	11 240.00	10 100.00	9 800.00
Heat cons.,[1] B.t.u. per kw. hr.	30 530.00	19 700.00	16 340.00	14 675.00	14 300.00
Heat cons.,[1] B.t.u. per i.h.p. hr.	11 180.00	10 600.00	9 050.00	8 460.00	8 295.00
Thermal efficiency per cent brake	12.58	18.84	21.66	25.21	25.97
Thermal efficiency, per cent elec.	11.16	17.32	20.9	23.25	23.85
Thermal efficiency, per cent indic	22.75	24.1	28.14	30.1	30.7

EQUIVALENT COAL CONSUMPTION[2] FOR VARIOUS PRODUCER EFFICIENCIES

POUNDS PER UNIT HOUR

Producer effic. per cent						
100 per cent	brake horse power hour.	1.413	0.944	0.785	0.705	0.685
	kilowatt hour	2.13	1.376	1.141	1.025	0.999
80 per cent	brake horse power hour.	1.766	1.181	0.980	0.882	0.857
	kilowatt hour	2.663	1.720	1.426	1.281	1.250
70 per cent	brake horse power hour.	2.015	1.347	1.120	1.006	0.977
	kilowatt hour	3.040	1.964	1.63	1.465	1.426

[1] Assuming same coal used on test—14 321 B.t.u.

[2] Standard Gas—106.4 B.t.u. (effective), 62 degrees 30 inches Hg.

with the aid of the generator efficiency curve Fig. 10, explained later. It will be noted that with full load on the engine, the efficiency approximates 10 100 B.t.u. per brake horse power hour and

[1] This heat value is considerably lower than the average during the 51-hour test, due largely to the condition of the fires. The holder tests were not run until after the long test had been completed; that is, after a continuous run at full load, of 51 hours equivalent to a week's regular shop load. However, the "low" gas made had no perceptible effect on the engine, except to require a slightly different mixture.

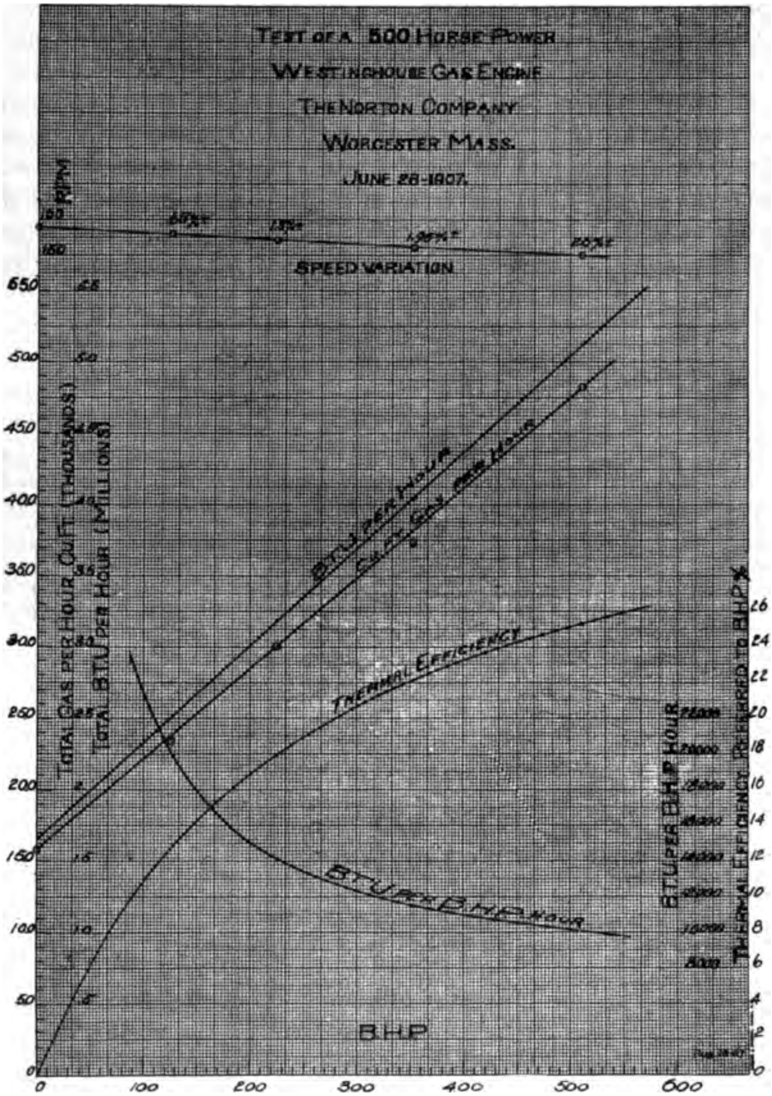

FIG. 2
TEST OF A 500 HORSE POWER WESTINGHOUSE GAS ENGINE

at a load of about 600 horse power, which was sustained for a few moments to test the rheostat, would be 9500 B.t.u. per brake horse power hour.

8 Table 2 presents data on heat consumption and efficiency at even engine ratings, interpolated from Fig. 2, from which it appears that the variations in heat consumption are well within normal limits imposed by present gas engine practice. Between three-fourths and over-load, which corresponds to the range in load generally experienced at the Norton plant, the heat consumption varied but 6¾ per cent from mean.

TABLE No. 3 51-HOUR TEST

SUMMARY OF RESULTS NORTON CO., JUNE 24-26, 1907

	LOAD kilowatt	WATER cubic feet	OIL gallons	COAL[a] pounds
Quantity at finish	363 550.0	94 900.0	2.875	23 775
Quantity at start	345 710.0	63 560.0		
Difference	16 840.0	31 340.0	2.875	23 775
Correction	+117.3			
Corrected difference	16 957.3	31 340.0	2.875	23 775
Elapsed time	51 hrs.	50 hrs.	48 hrs.	51 hrs.
Rate per hour	332.5	626.8	0.06	466[b]

	WATER cu. ft.	WATER gal.	OIL gallons	COAL pounds
Rate per kw-hr (332.5 kw.)	1.885	14.12	0.00018	1.402
Rate per b.h.p. hr (482.9 b.h.p.)	1.3	9.74	0.000125	0.965
Rate per i.h.p. hr (579.0 i.h.p.)	1.078	8.075	0.000104	0.805

[a]Clearfield run-of-mine—14 321 B.t.u. per pound as fired. Average thermal efficiency of plant, 18.43 per cent; engine, 24.93 per cent; producer, 73.81 per cent.

[b]See Appendix for discussion of relative condition of fuel bed before and after test and resulting heat correction.

Average gasification rate, 13.36 pounds per square foot per hour.

9 It is of interest in connection with the 51-hour test later treated to compute the coal consumption equivalent to the heat consumption shown in these holder drop tests. This has been done in the table for various producer efficiencies. With a perfect producer, the engine coal consumption at full engine rating, would be about 1 pound per kilowatt hour; at 80 per cent efficiency, 1¼ pounds; and at an efficiency of 70 per cent, slightly under 1½ pounds, or nearly 1 pound per brake horse power hour.

10 The foregoing data are of course, based upon several tests at different loads, and one of the best indications of their relative accuracy, as well as of the general efficiency of the engine from a thermodynamic standpoint, is the fact that the total heat consumption line is straight, not curved (convex to the X-axis); in other words the losses, internal and external, are practically constant.[1]

11 It should be borne in mind that in these fractional load runs no attempt was made to vary the ignition point to suit the light loads and thus to obtain the most efficient card for each load. Here again tests results have been sacrificed to record actual operating conditions, and the curves truly represent the change in efficiency that would occur during rapidly changing loads on the plant.

12 The mechanical efficiency was determined from these tests, as well as from the 51-hour test. But as it was impracticable to change springs for the lighter loads, the cards at these loads carry a greater possibility of error. However, the results are quite consistent.

13 These holder drop tests show a mechanical efficiency of 83.6 per cent at a load of 483 brake horse power which corresponds to the average sustained during the 51-hour test, while the latter shows an average mechanical efficiency of 83.46 per cent (see Fig. 6). On a basis of indicated horse power the heat consumption of the engine works out 8460 B.t.u. per hour at full load, or a thermal efficiency in the cylinders of 30.1 per cent.

51-HOUR TEST

14 In order to eliminate the mass of observations which would otherwise be necessary to follow the operations during the long test, the principal quantities have been plotted in Sheets No. 3 and 4, the latter showing gas analyses and the general effect of varying water gas runs. All continuous quantities, as kilowatt output, water and coal, are plotted at a given time as the average for the preceding periods; hence, the brake horse power deduced from average kilowatt *should not necessarily coincide* with brake horse power deduced from instantaneous kilo volt ampere reading at the same hours. It is noteworthy, however, that the average of ¼ hour kilo volt ampere readings checked within 3.5 kilowatts with the average

[1] Thus, if the X-axis (load) were elevated to a point (Y = 1 650 000) on the Y-axis (heat input to the engine), that is, neglecting fractional load losses, the *heat consumption is practically proportional to the load*, or 6800 B. t.u. per brake horse power hour, a *constant at all loads.*

TABLE NO. 4 51-HOUR TEST—6-HOUR AVERAGES CORRECTED DATA ONLY

PERIOD	JUNE 24, P.M.		A.M. JUNE 25 P.M.				A.M. JUNE 26 P.M.			TOTAL AVERAGE
	3–6	6–12	12–6	6–12	12–6	6–12	12–6	6–12	12–6	51 hours
Load										
Kw. by wattmeter	303.6	358.9	347.25	333.1	320.3	354.5	338.85	322.0	319.0	332.2
Kilo-volt-amperes	306.2	354.9	352.9	336.4	306.2	335.3	338.2	317.7	310.7	328.72
B.h.p. from kw	440.7	522.2	504.8	483.8	451.5	487.4	492.2	467.3	462.8	482.3
B.h.p. from k.v.a.	445.0	516.4	512.7	498.5	445.0	487.0	491.5	461.0	451.0	477.31
Amperes	1290.0	1412.0	1411.0	1382.0	1250.0	1341.0	1353.0	1302.0	1276.0	1335.2
Volts	237.3	251.1	250.1	243.5	245.0	250.0	250.0	244.0	243.3	246.03
Coal										
Lbs. fired per hour	443.5	454.7	455.3	466.00	475.0	463.8	449.7	522.0	452.0	466.0
Lbs. fired per sq. ft. per hour[1]	12.71	13.04	13.06	13.36	13.63	13.30	12.90	14.97	12.96	13.36
Water										
Cu. ft. per hour	613.3	594.1	613.3	595.3	592.6	653.1	652.0	651.0	677.0	626.8
Cu. ft. per kw-hr.	2.126	1.625	1.765	1.786	1.850	1.843	1.925	2.020	2.120	1.886
Gal. per b.h.p. hr.	10.43	8.53	9.100	9.200	9.260	10.04	9.270	10.44	10.95	9.740
Av. inlet temp.—deg. fahr.	65.00	65.50	65.00	65.40	66.30	67.00	66.00	66.60	67.30	66.01
Av. temp. rise—deg. fahr.	42.80	54.60	47.70	48.90	49.80	46.00	46.60	43.80	43.60	47.10
Gas										
Heat value by calorim.	112.3	109.16	108.0	116.7	119.4	113.5	111.8	119.3	120.9	114.56
Heat value by anal.		119.74	105.9	110.4	109.78	108.5	113.5	116.13	115.13	112.40
Heat value max.	123.2	122.60	122.1	125.8	125.6	117.1	116.3	122.8	126.0	126.00
Heat value min.	105.0	108.10	101.5	101.9	111.6	109.8	107.2	110.2	111.4	101.50

[1] Rate of gasification per square foot of fuel bed area of producers.

[2] Calorific values all reduced to effective at 62 deg. fahr. 30 inch Hg.

kilowatt recorded by the integrating wattmeters, 332.2 kilowatts. Similarly, the average gas analyses showed, within 2 B.t.u., the same calorific value as the average calorimeter readings—114.5 B.t.u. per cubic foot at 62 degrees fahr. and 30 inches barometer. These values are given in Table 3 and 4 summarizing the results of the 51-hour test. The latter gives the averages and total quantities for the entire period, the former the averages for the various six-hour periods.

15 From the general log, Fig. 3, it will be apparent that the load was maintained fairly uniform and as near rating as the fluctuations in the factory load would permit. During the night runs, it was possible to considerably exceed full rating; *e. g.*, on night shift, June 24, an average load of 522 brake horse power was carried for six hours—equivalent to nearly 20 per cent overload[1] on the generator with only 109 B.t.u. gas. The coal fired during the test, was fairly uniform in rate as shown by the log, Fig. 3, averaging 466 pounds per hour or 13.36 pounds per square foot of fuel bed area per hour. The calorific value of the gas was rather low during the night runs, but recovered during the day. This condition of affairs is largely attributable to the difference between the two producer men's methods of handling the fires. This low heat value did not, however, interfere in the least with the load which was heaviest when the gas ran as low as 104 B.t.u.

16 The water consumption naturally varied in inverse proportion to the temperature rise, as the inlet temperature was practically constant. No attempt was made to run the temperature of the jacket water to a very high point in order to increase the efficiency of the engine, but rather to maintain it at such a point as would best suit the load anticipated, as is the usual practice. The temperature rise could have been doubled without physical injury to the engine. In the gas log, Fig. 4, H and CH_4 are plotted to an increased scale in order to show the general effect of the length of the steaming period on the gas quality.

COAL CONSUMPTION

17 To facilitate the determination of the true amount of coal gasified during the 51-hour test, the fire was brought to the same

[1] During the noon hour Monday, while testing out the rheostat, a load slightly over 600 brake horse power was sustained by the engine for a few moments without indications of "stalling." This is equivalent to 20 per cent above the normal rating of the engine.

level and as near as possible to the same condition at the end as at the beginning of the run. Further, the test was not started until the fires had been subjected to normal rate of gasification for some time. A detailed discussion of the constitutents and relative heat value of the fuel bed before and after the test is taken up in the appendix and requires no further reference here.

18 The full load test was continued from Monday afternoon until Wednesday evening. A longer test would have undoubtedly been more desirable; but it should be borne in mind that the ordinary method of testing for periods of a week or more, usually followed out in the case of the continuous type of producer, could not be employed

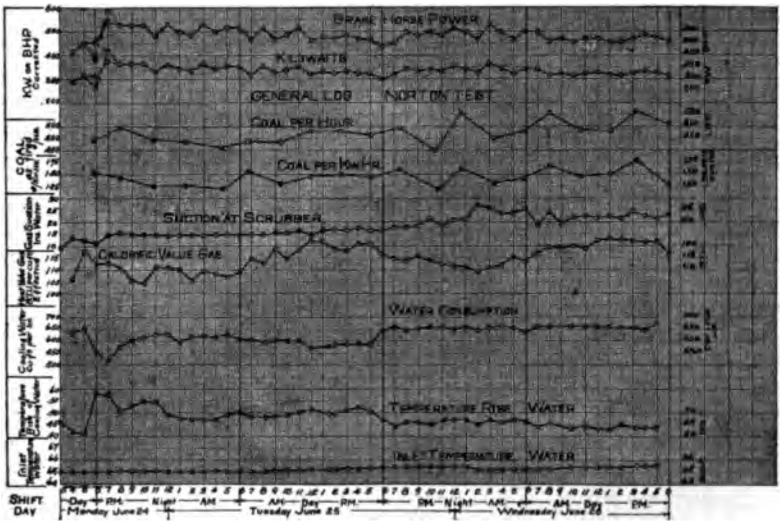

FIG. 3 GENERAL LOG NORTON TEST

here with the intermittent type, owing to the fact that the fires must be drawn at regular intervals for cleaning the producer. A normal week's run at this plant averages 54.4 hours (10-hour day). The test run of 51 hours is therefore practically equivalent to a normal week's operation; or, in other words, practically equivalent to the period which occurs between regular shut-downs for the removal of ash and renovation of fires. Table 3 gives the weight of coal actually used during the test, 1.402 pounds per kilowatt hour. Table 5 gives the calorific value of the numerous samples tested.

MECHANICAL EFFICIENCY AND INDICATOR CARDS

19 Owing to the great labor involved in indicating the engine at sufficiently short intervals to follow the variations in load, it was decided to indicate at intervals of about one hour, with the precaution of taking electrical readings at *exactly* the same time. These simultaneous values could then be plotted and an average value struck, which would represent the average mechanical efficiency.

TABLE NO. 5 FUEL ANALYSES

SAMPLE	NO.	VOLATILE MATTER	FIXED CARBON	MOISTURE	ASH	B.T.U. PER LB.	
						DRY	ACTUAL
Clearfield bituminous[1] used during test	1	19.15	73.50	0.85	6.5	14 313	14 181
	2	20.12	73.60	1.09	5.19	14 531	14 360
	3	20.40	73.30	0.70	5.6	14 407	14 306
	4	18.30	75.40	0.90	5.4	14 484	14 347
	7	20.78	73.20	0.60	5.42	14 531	14 445
	10	20.75	71.81	0.75	6.69	14 345	14 236
	15	19.70	74.79	0.90	4.61	14 594	14 457
	18	19.30	76.40	1.00	3.30	14 641	14 486
	20	20.43	71.41	1.05	7.11	14 232	14 069
Avg. of 9 samples		19.87	73.71	0.87	5.54	14 450	14 321
Anthracite for building fires		5.20	78.95	3.20	12.65	12 709	12 320
Ash anthracite[2]			88.25	1.15	10.6	11 977	11 840
from under clinker			87.80	1.40	10.8	11 946	11 780
including ash in producer ash pits			88.30	0.70	11.0	11 946	11 850
Averages			88.12	1.08	10.8	11 956	11 823

[1] Sulphur in Clearfield samples 2, 1.05 per cent; 10, 0.75 per cent; 20, 0.69 per cent; Average, 0.83 per cent.
[2] See section of producer bed, Fig. 12.

20 The results are shown in Fig. 6, covering 72 sets of cards taken regularly during the tests. This method of determining the characteristic of the engine is probably more accurate than taking three or four times the number of cards and averaging them. By the graphical method, unreasonably high or low values may be quickly recognized and allowed for in the average. Moreover, the reason for these high or low values may readily be traced back to some

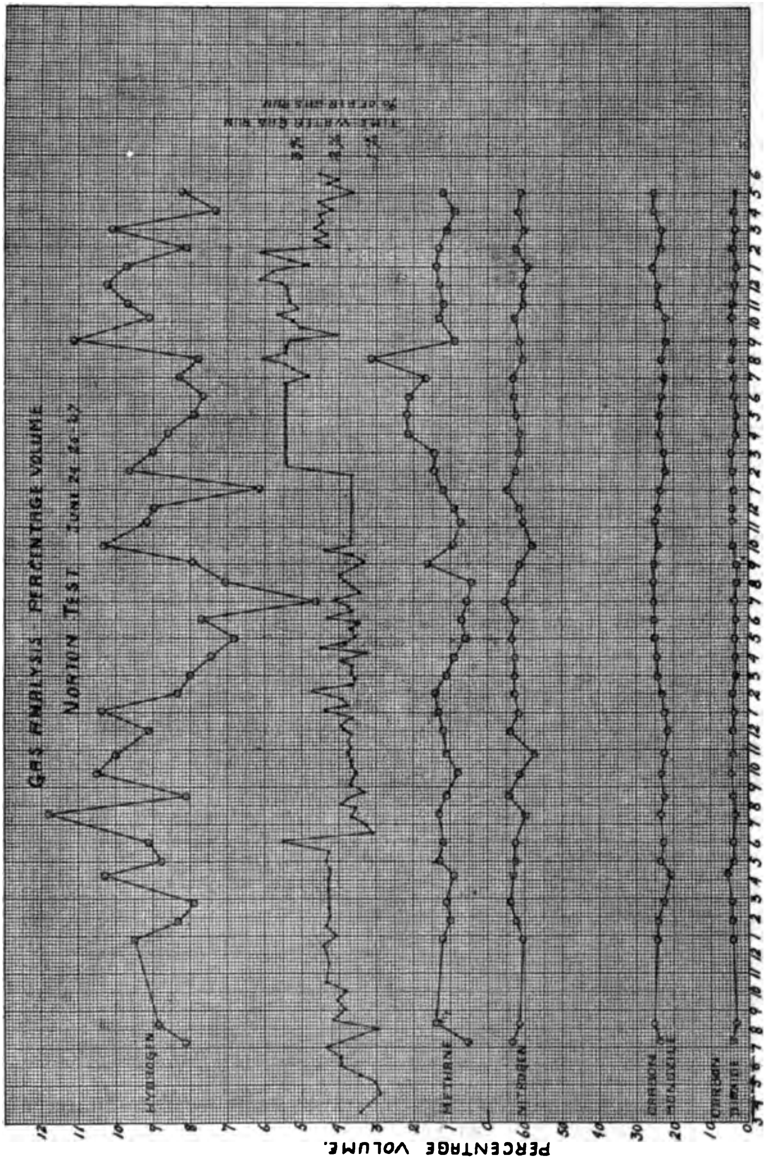

FIG. 4 GAS ANALYSIS PERCENTAGE VOLUME

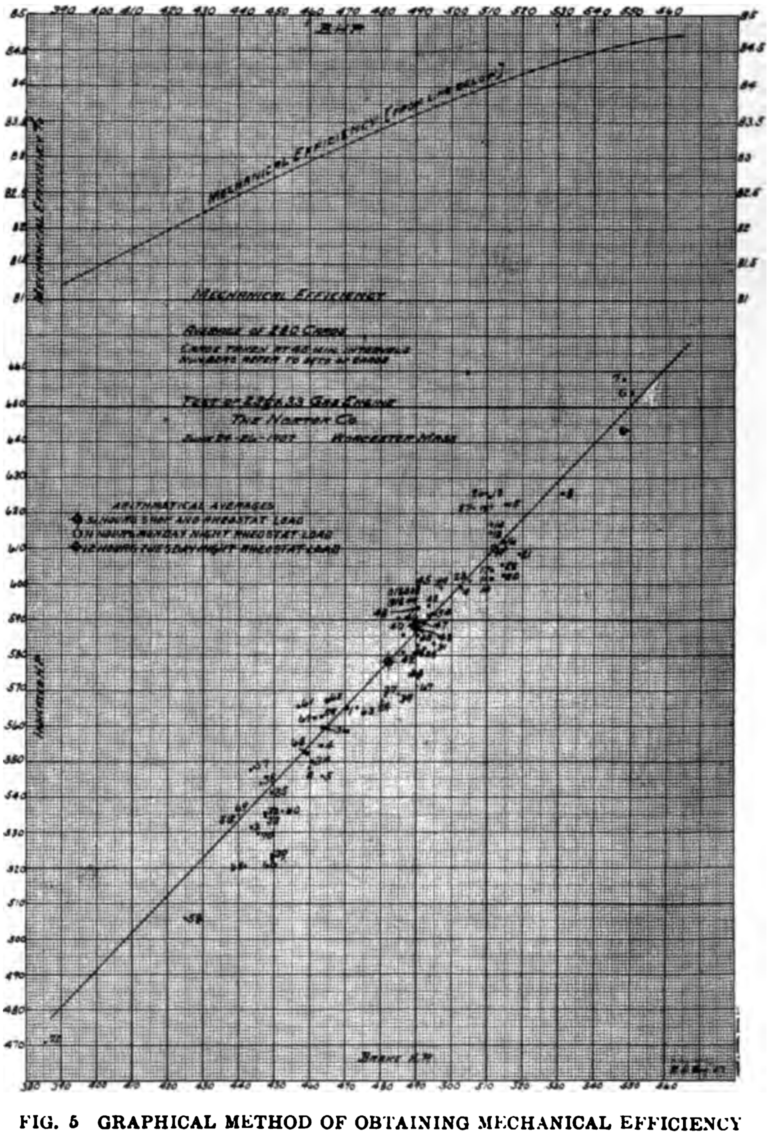

FIG. 5 GRAPHICAL METHOD OF OBTAINING MECHANICAL EFFICIENCY AT VARIOUS LOADS

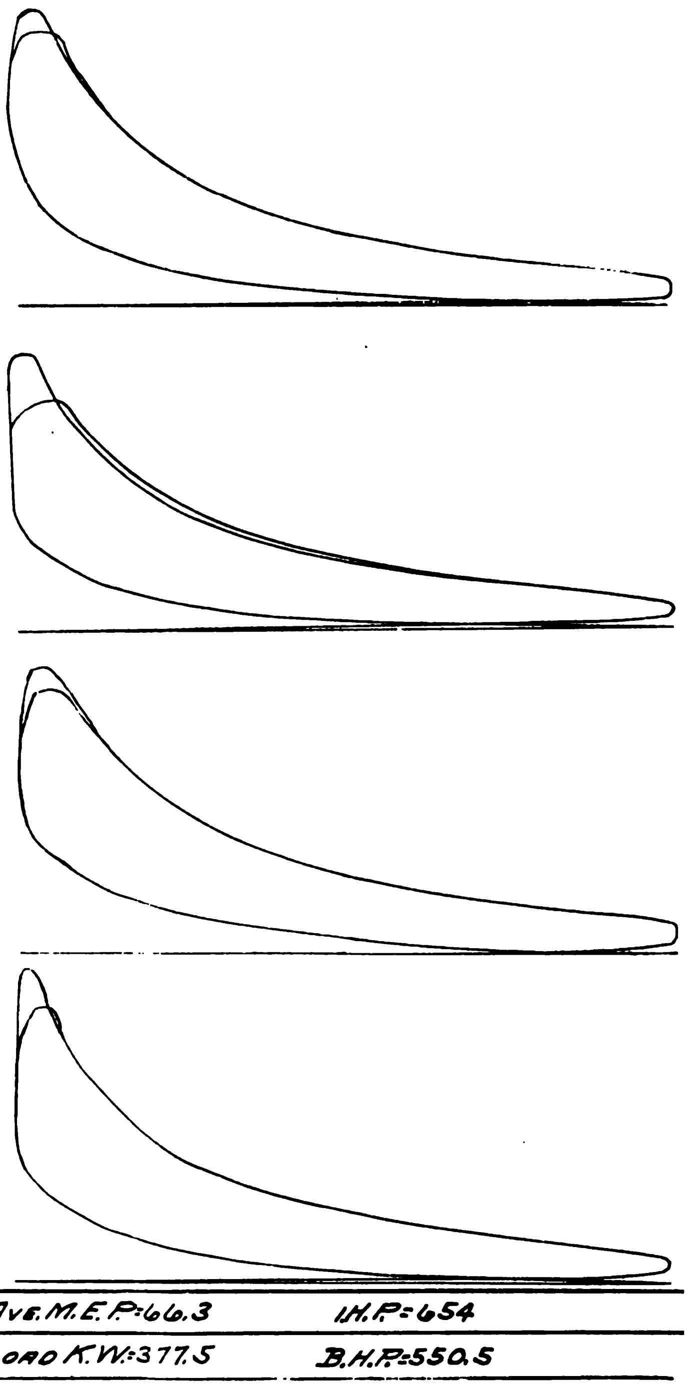

FIG. 6. INDICATOR CARDS SHOWING VARIATION OF LOAD. SET 6

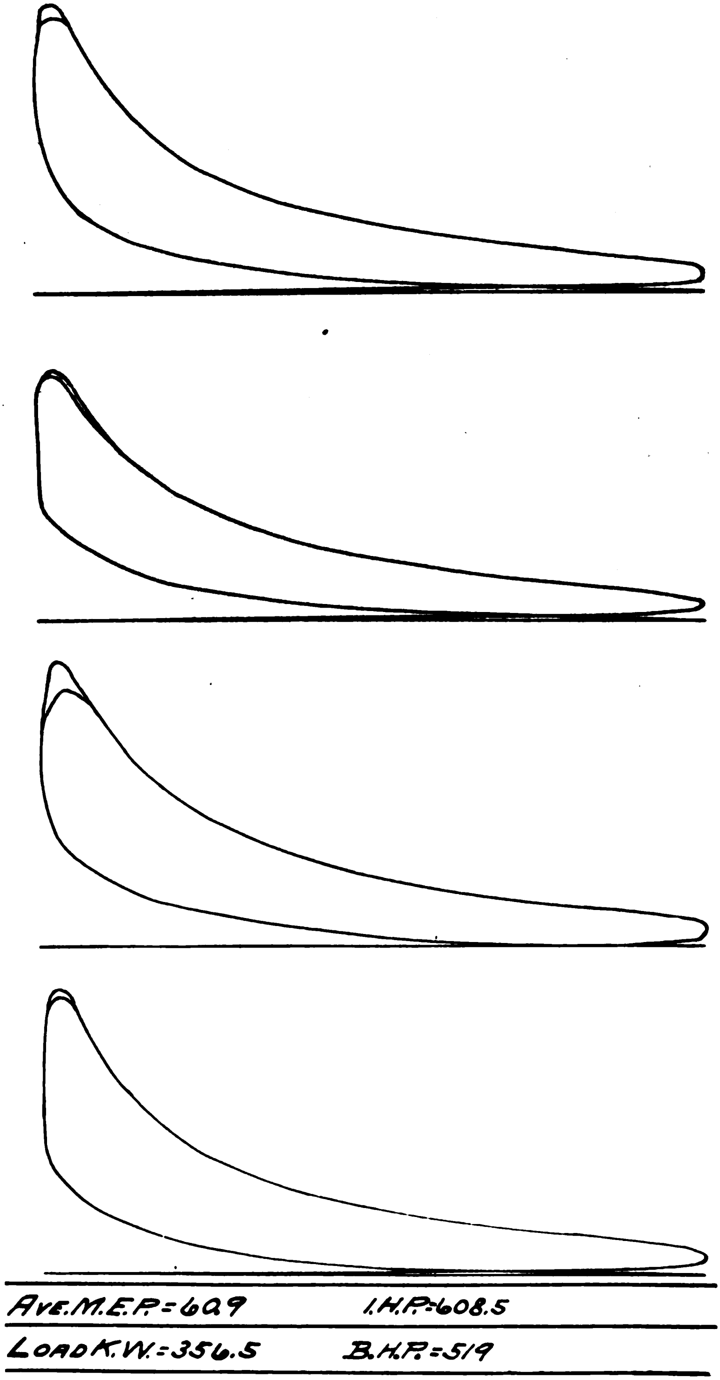

FIG. 6 INDICATOR CARDS SHOWING VARIATION OF LOAD. SET 21

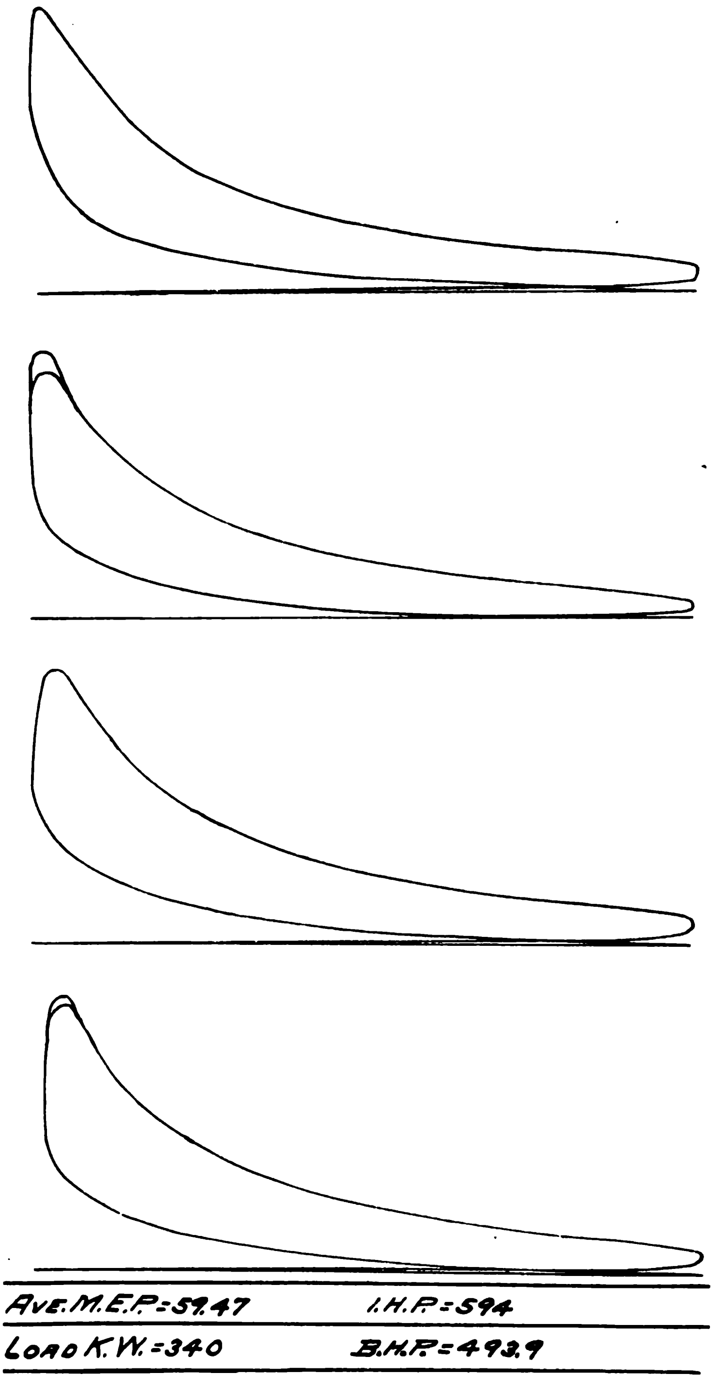

FIG. 6 INDICATOR CARDS SHOWING VARIATION OF LOAD. SET 52

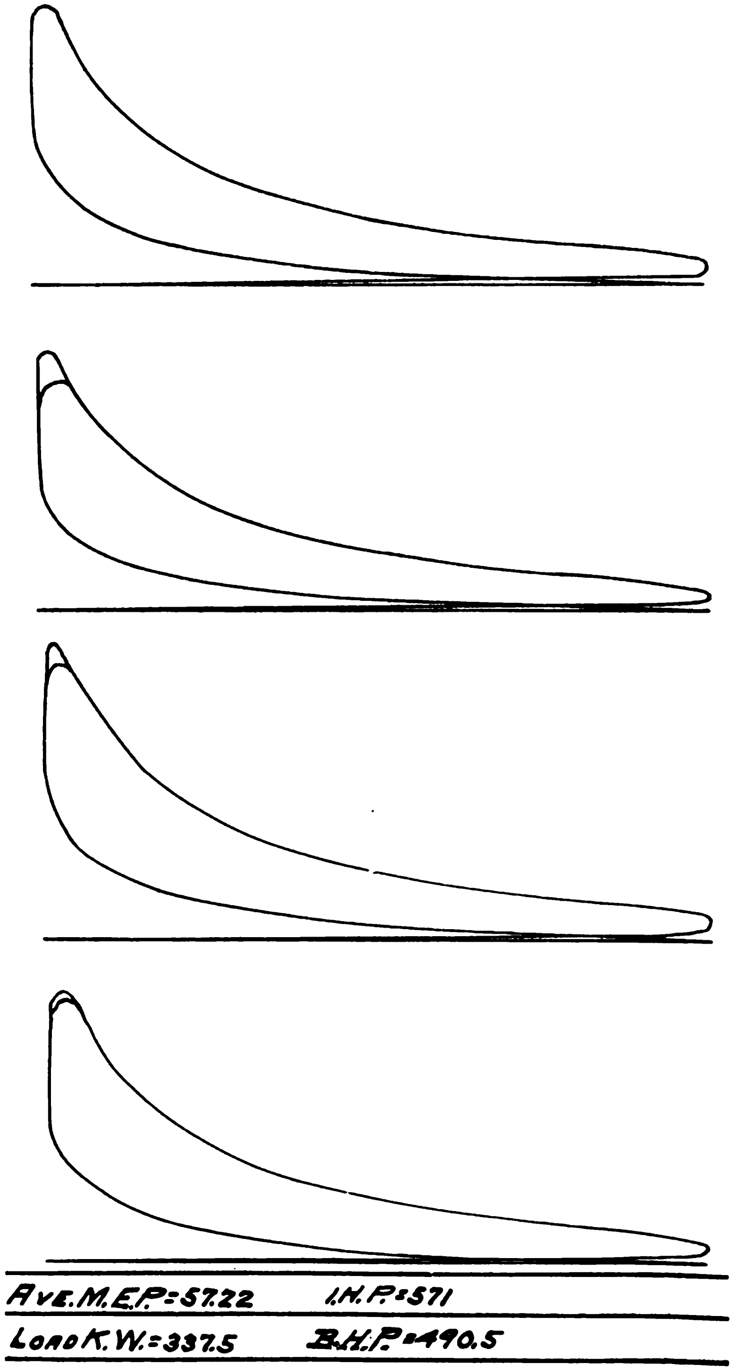

FIG. 6 INDICATOR CARDS SHOWING VARIATION OF LOAD, SET 67

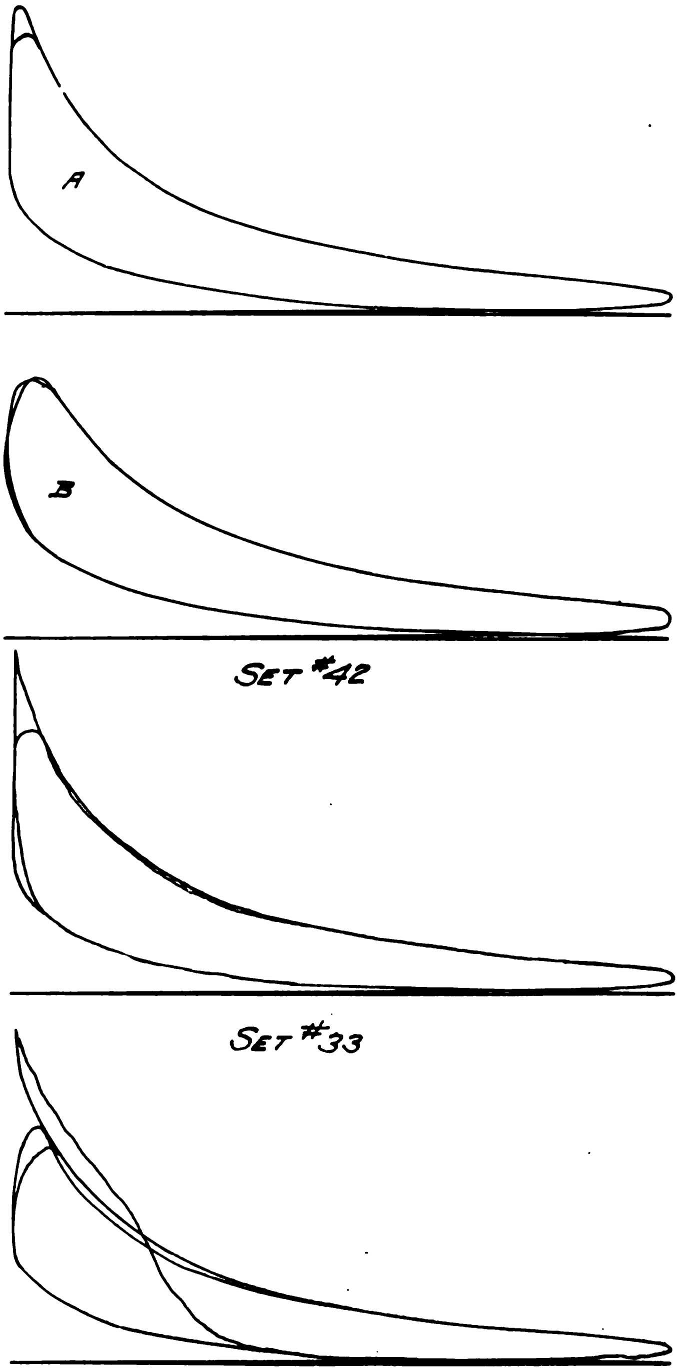

FIG. 6 INDICATOR CARDS SHOWING VARIATION OF LOAD. SET 39

peculiarity of the card and allowed for; whereas, any error would probably not have been discovered by the method of averages.

21 To check this graphical method, however, three arithmetical averages are plotted on Fig. 5, the one x the average for the entire 51 hours, the others y and z, the averages for a period of 11 hours, beginning Monday evening, during which load was maintained prac-

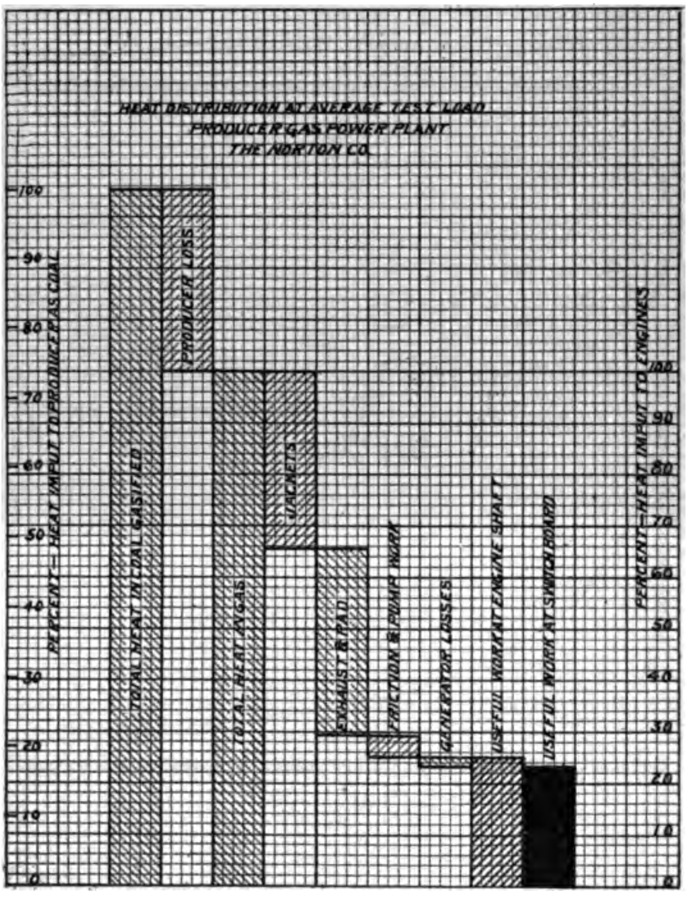

FIG. 7 HEAT DISTRIBUTION AT AVERAGE TEST LOAD

tically constant by rheostat, and a similar period of 12 hours Tuesday also on rheostat load. The fact that these points agree very closely with the curve, illustrates the reasonableness of the graphical method.

22 The average mechanical efficiency derived from Fig. 5 is at the average load carried, 83.5 per cent, or at full load, 83.8 per cent. Although here drawn to a large scale, the efficiency curve is very

flat, lying between 83 and 84 per cent from 460 to 510 horse powei. This efficiency includes, of course, all pump work.

23 For example, the sets of cards taken during the test are shown on Fig. 6. Slight differences are apparent between the several cards of each set, due to the lack of close, individual adjustment of igniters, which was not attempted, as the engine was tested in its normal condition. These cards show a mean effective pressure within the range of load carried, of from 55 to 65 pounds per square inch. For maximum loads, the mean effective pressure rose to 67 and 68 pounds. A study of the cards shows plainly that the "peaked" cards do not give the highest mean effective pressure. This is illustrated by the two cards from Set 39, *A* and *B*. Both are excellent cards, and of almost the same mean effective pressure, the fatter card, *B*, showing if anything, to better advantage. In the majority of cases, it appears that if the card loses its "peak" for any reason, the expansion line rises sufficiently to compensate therefor. Thus, in card 2, Set 6, the "flat" card shows 4 per cent higher mean effective pressure than the "peaked" card. Again, the "feat" card 42, gives 2.5 per cent higher mean effective pressure than the "peaked." This is further shown in extreme form in card 33, which traces a "premature."

24 "Prematures" and backfires occurred at various times during the test, sometimes rather frequently, but mostly at intervals of several hours, none of which appeared to affect the operation of the engine. In regard to these, there seemed to exist throughout the test a definite relation between the occurrence of backfires and the charging of fresh fuel in large quantities, apparently indicating the presence of rich hydrocarbon volatiles, which it was impossible to segregate with the analytical apparatus available.

HEAT BALANCE

25 From the various quantities observed and derived, it is now possible to obtain partial heat balance of the complete plant at the

TABLE NO. 6 DISTRIBUTION OF HEAT AT AVERAGE TEST LOAD

	ENGINE ONLY		ENTIRE PLANT	
	Brake	Elec.	Brake	Elec.
Useful work	24.9	22.98	18.38	16.97
Electrical losses		1.92		1.41
Friction and pump work	4.58	4.58	3.37	3.37
Jacket absorption	34.22	34.22	25.22	25.22
Exhaust and radiation (by bal.)	36.3	36.3	26.81	26.81
Loss in producer			26.22	26.22
	100.00	100.00	100.00	100.00

average test load, 483 brake horse power. Knowing the useful work, jacket absorption, mechanical efficiency, electrical losses and producer losses, the remainder may be assigned to exhaust and radiation, as there are no losses of any magnitude in the producer gas system corresponding, for instance, to condensation and leakage

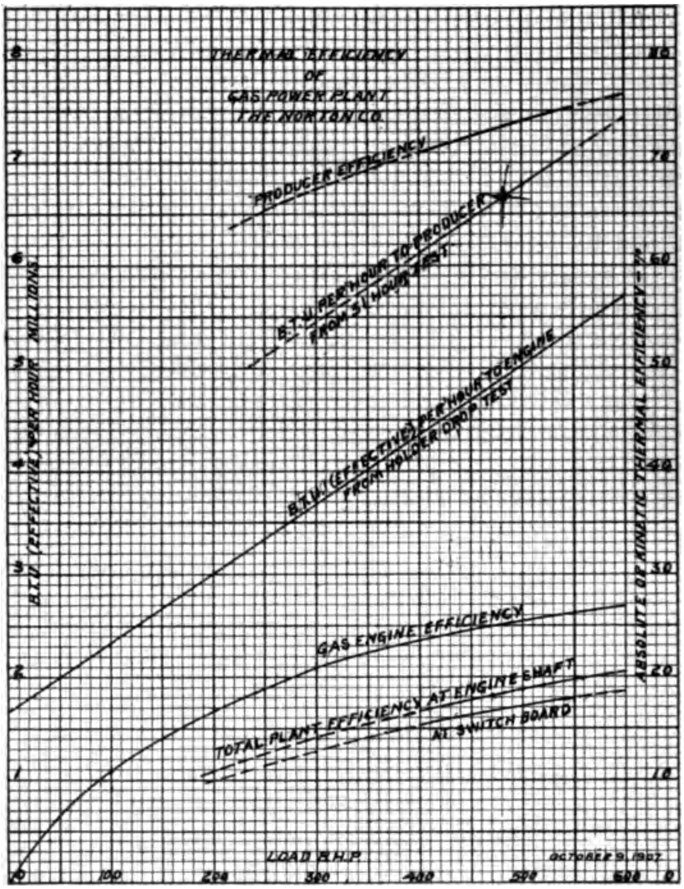

FIG. 8 THERMAL EFFICIENCY OF GAS POWER PLANT

in a high pressure steam system. This heat balance is given in Table 6, and in graphical form in Fig. 7. This balance shows that practically one-fourth of the heat delivered to the engine by the producer is converted into useful work at the engine shaft, or 23 per cent at the generator terminals. It also shows a moderate jacket absorption, considering the small temperature rise. It should not be inferred that with higher water temperatures the relative percentage of jacket absorbtion and exhaust will reverse. It has been shown by experiment on both small and large engines that the decrease in

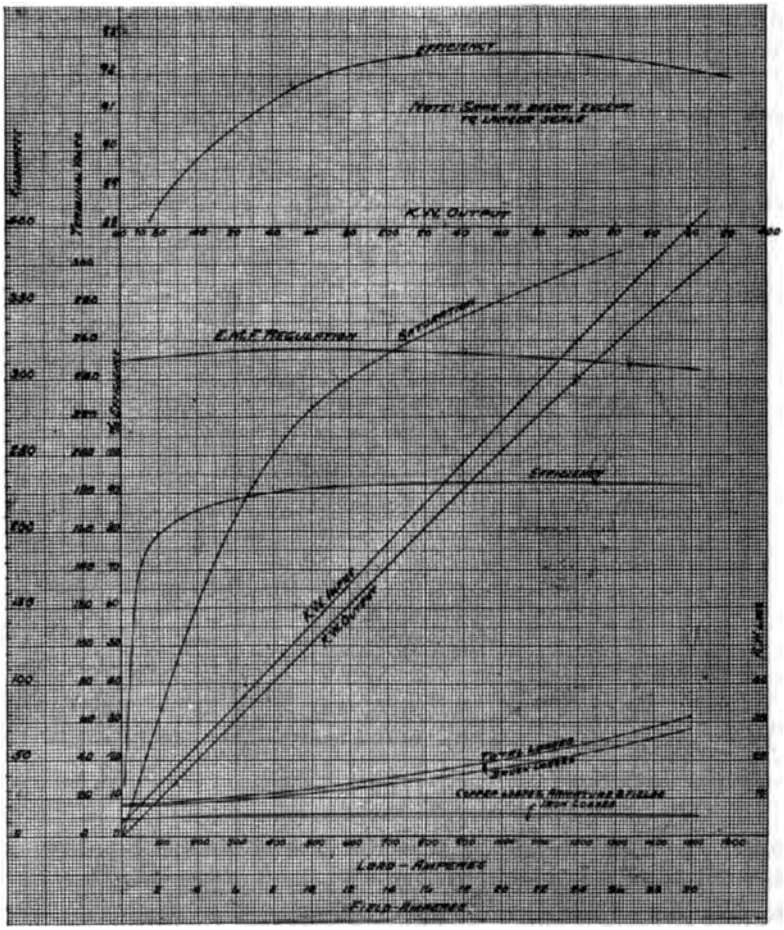

FIG. 9 GENERATOR TEST RECORD
300 KW. 250 VOLT DIRECT CURRENT COMPOUND WOUND GENERATOR

jacket absorbtion very largely appears as increased work and hence increased efficiency.

PRODUCER AND PLANT EFFICIENCY

26 Upon the basis of the above heat balance the segregated efficiencies of the principal parts of the plant over the range of load

carried in its normal operation may be determined, with a single assumption—that the losses in the producer bear a constant relation to the weight of coal fed into the producer; that is, to the heat input. This has been worked out on Fig. 8, and for the short range in loading from 400 to 550 brake horse power, it is believed the assumption is reasonable.

27 Starting with the total heat consumption line of the engine, as determined from the holder drop tests, the corresponding total

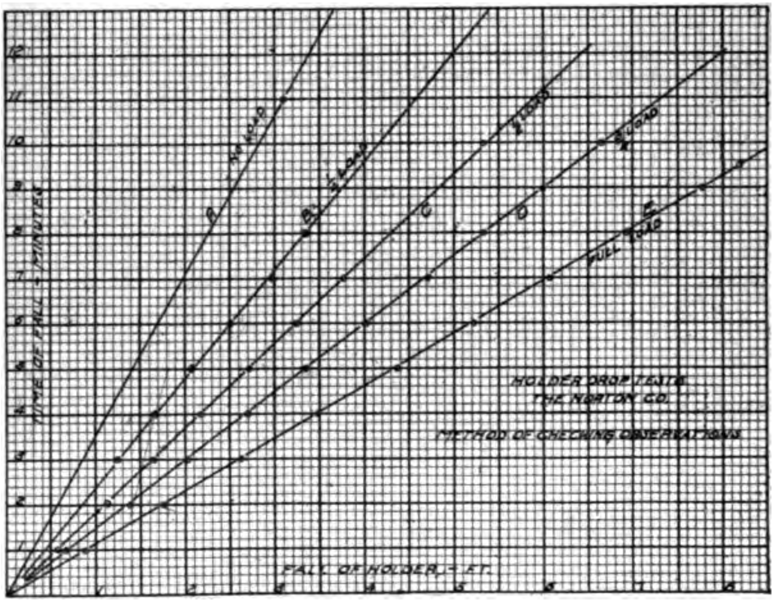

FIG. 10 HOLDER DROP TEST
METHOD OF CHECKING OBSERVATIONS

heat consumption of the plant, in the form of coal fed into the producer, may be represented by a parallel line. From these two total heat lines, the thermal efficiency curve of the plant, engine and producer, are respectively derived. At full load, the complete plant turns 18.5 per cent of the heat in the fuel into work at the shaft, or 17.1 per cent at the switchboard; and at this load the producer efficiency is 74.1 per cent, as compared to 73.8 per cent average for the 51-hour test.

GAS CHARACTERISTICS

28 The variations in gas from time to time are shown in Fig. 4 only as averages for hourly periods. Table 4 gives corresponding

maxima and minima for six-hour periods. Thus, the extreme limits of variation during the test range from 101 to 126 B.t.u. (effective) per cubic foot, or 10 per cent above and 11 per cent below the mean value for the entire test.

29 The relative effect of water gas and air gas runs is shown in the gas log Fig. 4. Although the hydrogen at the engine is not instantaneously responsive to an increase in water gas, yet in general the average hydrogen content follows the percentage water gas quite perceptibly. Most of the water gas runs continued for 30 seconds, though toward the end 20-second runs were made at short intervals, resulting in an increase in H, but to 11 per cent only. This suggests the possibility of improving the gas by short, heavy blasts, and cor-

TABLE NO. 7 SPEED VARIATION TESTS

Speed, r.p.m.	155	154.0	152.0	150.0	149.0	148.0
Volts	255	255.0	257.0	258.0	258.0	257.0
Amperes		327.5	665.0	955.0	1303.0	1347.0
Kw		86.1	170.8	246.6	336.1	346.0
B.h.p.		129.6	247.6	356.5	489.3	503.0
Per cent full rating		25.9	49.5	71.2	97.9	100.5
Speed drop, per cent ± mean		0.819	0.958	1.597	1.916	2.236

Instantaneous Load Test June 27, 1907, 6 p.m.

No-load to full-load, 280 volts, 1190 amperes, 345 kilowatts, 502 brake horse power.

No-load speed	155 revolutions per minute.
Load thrown on	148 revolutions per minute.
Load thrown off	155 revolutions per minute.
Difference	7 revolutions per minute.
Speed variation	4.6 per cent of total — 2.3 per cent ± mean speed

respondingly brief periods of steaming; provided, of course, there is sufficient holder capacity to absorb the variations in gas production.

30 CO_2 records, were taken to follow any changes in the gas that could not be caught by hourly analyses. During the time the apparatus was in action the variations were small, agreeing quite closely with the analyses. The CO_2 record gave a rough indication of the condition of the fire, and showed an abnormal percentage of CO_2 with excessive air supply drawn in during the period of blast.

31 The measurements of dust, or suspended matter, showed a large reduction of total impurities between wet scrubber outlet and engine. It is quite apparent from the appearance of these samples that a large proportion of the lampblack passing the wet scrubber

finds its way to the engine in spite of the dry scrubber and the opportunity for settling in the holder, but without deleterious effect on either the operation or efficiency of the engine.

SPEED REGULATION

32 Three independent observations give data on speed regulation:

a Speed during holder drop tests, Fig. 2.

b Speed variation tests at various loads, Table 7.

c Instantaneous speed variation test, also Table 7.

These agree closely, although taken on different days. Thus, at full engine load, the drop in speed from no load to full load, was: *a* 2.6 per cent, *b* 2.24 per cent, *c* 2.3 per cent. Fig. 2 shows the speed characteristics practically a straight line without any drooping tendency at the heavier loads. This indicates a good margin of overload capacity.

GENERATOR TESTS

33 Owing to the existence of detailed records of tests on the generator at the builder's works, these were adopted with the precaution of checking same by independent recalculation of efficiency, not only at rated voltage, but also at 240 and 230 volts. These efficiencies include iron and copper losses (in armature and field, both series and shunt) and brush losses (I^2R + friction). As the generator was proportioned so as to give maximum efficiency at average shop load (270 to 310 kw.), the efficiency during the 51-hour test was somewhat lower, 92.3 per cent, an entirely reasonable figure for a machine of this size.

34 Temperature rise was recorded by the thermometer applied to the shunt field coil. The maximum observed was 167 degrees fahr. with room temperature 92.5 degrees fahr., giving a rise of 74.5 degrees fahr., or 41.4 degrees cent. During the preceding three hours, the generator sustained a load of from 365 to 375 kilowatts (25 per cent above rating) immediately following several hours run at full load. This rise is not abnormal, considering the high engine room temperature, for which reason the average load during the test was carried somewhat lower than would have been the case during cooler weather.

APPENDIX

METHODS OF TESTING

35 As the Norton plant regularly operates only ten hours per day from 7:00 a.m. to 12:00, and 1:00 p.m. to 6:00 p.m., it was decided to maintain the plant at full load during the normal standby period. Otherwise the intangible effect of standby losses would interfere to a considerable degree with the accuracy of the net operating results desired.

LOAD

36 Load control was secured by means of a water rheostat especially constructed for the purpose, and possessing sufficient flexibility to bring the average shop load up to approximately full rating, and at night to maintain the full load. This method, and the particular type of rheostat used proved very successful. During the night, an almost constant load could be maintained. During the day, however, it was impossible to operate at so high an average load, owing to the fluctuations from shop motors, which, in addition to the rheostat load, would otherwise overload the plant. Furthermore, the excessive atmospheric temperature, 90 to 96 degrees fahr. in the engine room, during the period covered by the test, made it undesirable especially during the day to carry heavier load. At times, when the shop load was fairly quiescent, the rheostat was used to bring it up to the desired average.

SIGNALING

37 Signaling was accomplished by means of an electric bell, with repeaters in the producer room and outside at the gas holder. A five-minute "attention" signal brought the various observers to their places. Observations commenced at the five-second "preparatory" signal and were recorded after the "final" signal. This method proved to be especially valuable during the holder drop tests, as all observers were simultaneously apprized of the other's movements, which eliminated the necessity of synchronizing watches.

FREQUENCY OF READINGS

38 At 15-minute intervals-ammeter, voltmeter, gas calorimeter; 30-minute intervals—scrubber suction and water gas runs; 45-minute intervals—indicators, wattmeters, watermeters, temperatures, ba-

rometer, pressures and speeds; 60-minute intervals—gas analyses; every two hours—coal weights, as required.

OUTPUT

39 Electrical instruments were used entirely to measure output. Switchboard ammeter, integrating wattmeter and standard Weston voltmeter readings were simultaneously observed for an independent

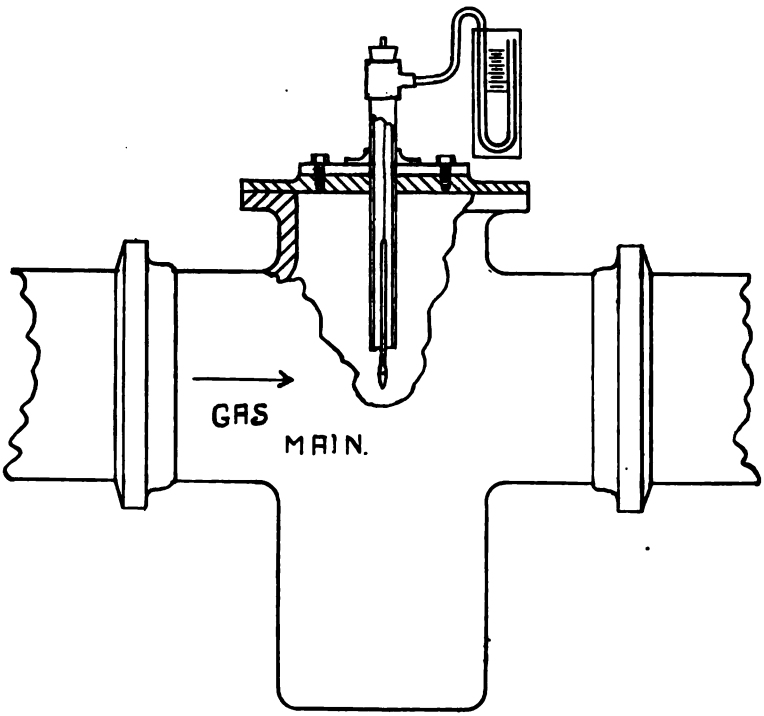

FIG. 11
APPARATUS FOR MEASURING GAS PRESSURE AND TEMPERATURE

check. The load meters were calibrated at the close of the test by means of a standard Weston shunt and mill-voltmeter, showing a uniform calibration error.

BRAKE HORSE POWER

40 In all cases, the brake horse power was calculated from kilowatt readings showing by the generator efficiency curve, Fig. 9, which is based upon the efficiency tests formerly made on this par-

ticular machine. The distribution of losses, however, was again checked at various loads and substantially agreed with the curve.

INDICATED HORSE POWER

41 Indicated horse power was determined by four indicators of the outside-spring type, manipulated simultaneously at the given signal. The preparatory interval of five seconds was allowed for opening indicator cocks, so that very little opportunity existed for gumming of indicators, which were carefully cleaned several times during each shift. Electrical readings were also taken at exactly the same time so that no opportunity should exist for a change of load.

42 In order to obtain more representative cards, two cards were traced *before lifting the pencil*. They were then integrated separately, and averaged, if any difference appeared, which was quite often the case. In all cases, the atmospheric line was traced *immediately after* the card was taken—not before. This precaution is intended to compensate for the slight expansion taking place when the indicator was being heated. The indicator rigging was a permanent fixture of the engine. With the lost motion absorbed by the strong spring, very little opportunity existed for distortion of cards.

SPEED

43 Speed was measured both by tachometer and speed counter. The tachometer, a Schaeffer-Budenberg centrifugal instrument, was belted to the main engine shaft so as to be close to the last observer of the indicators, who noted the instantaneous speed immediately after releasing the indicator. At the same time the speed was counted from the engine lay shaft by the signal man, so that very little opportunity occurred for change. These observations checked closely.

TEMPERATURES

44 Temperatures were determined by ordinary chemical thermometers, checked in hot and cold water baths for accuracy. As all of the temperature measurements, excepting calorimeter temperatures involved inappreciable errors, considering the character of results desired, no attempt at extreme accuracy was made in the thermometry of the test.

PRESSURES

45 Gages of the U-tube, or manometer type, were installed at the engine throttle, gas supply-line and holder, Fig. 1. Except for cyclical fluctuations, due to engine suction, the pressure was practically constant at all points, owing to the uniform weight of the holder. Barometric pressure was read by vernier in the engine room, and checked by Weather Bureau observations reduced to proper level. In the final results, all gas readings have been reduced[1] to standard conditions, 62 degrees fahr. and 30 inches barometer, taking also into account the excess pressure above atmosphere, shown by the several manometers. These reductions were necessary before consistent results could be expected in the gas consumption line, Fig. 2, as gas came to the engine unusually hot 92 degrees fahr. during the day. The lower or effective heat value has been used in all cases, as explained elsewhere.

GAS SAMPLING

46 Gas sampling was done as close to the engine as convenient, not more than 25 feet of piping intervening between the point of sampling and the throttle. See Fig. 1. Moreover, the samples were drawn from the center of the main by means of an extension tube. A standard Junker calorimeter was employed with thermometers indicating to 0.01 degrees cent. with close reading lens. For analysis, a modified Orsat, or Hempel, apparatus was employed with explosion bulb for H and CH_4. In addition, an "Ados" automatic CO_2 recording apparatus was in operation during the entire time.

COOLING WATER

47 Jacket water was measured by a Keystone meter. Being practically a new meter, its possibility of error was not taken into consideration, especially as the resulting data were only incidental to the test. Care was taken to observe the temperatures of engine inlet and overflow water sufficiently close to the engine to avoid any appreciable radiation loss. As it was impossible to measure the temperature and quantity of each hot water outlet at the engine, the outlet thermometer was so located in the discharge main as to insure

[1] McFarland's "Reduction Factor for Gases."

a thorough mixing of several hot water outlets from pistons and jackets before reaching the thermometer, Fig. 1.

HOLDER DROP TESTS

48 The method employed during the holder drop tests was based upon the observations of the *rate of fall* of the holder with the gas supply from the producer *entirely shut off* and the engine running at a definite load. Previous to each test, the engine was maintained at its load for ten minutes or more, and at a given signal, the producer was cut off by valves, electrical readings taken and the fall of the holder measured by tape and stop watch. Observations were not begun until the holder had fallen an inch or two and attained a definite rate. The stop watch was then set as the index passed a given division and the readings were recorded at ten-second intervals until the release signal. These readings were then plotted to time and fall, which gave at once a visual indication of the correctness of the readings, not to be attained by using simply the first and last readings of the tape. See Fig. 10.

49 It is obvious, that the slightest irregularity in the fall of the holder due to sticking along the ways, or unequal depression from any cause would easily have been detected by observations falling irregularly on the plot. This graphical method also shows at a glance whether the gas consumption of the engine at a constant load, is uniform within short intervals of time.

50 Fig. 12 shows also the method of measuring the temperature and pressure at the holder. At the position shown, there could be no question as to the accuracy of the temperature measurement. Even in lifting out the thermometer for reading the rush of gas practically eliminated the cooling effect of the pipe walls. Owing to the effect which the heat of the sun would have on the dimension of the holder, the holder drop tests were made after sundown with a strong wind blowing, which served to equalize perfectly the atmospheric temperature.

51 A decisive check on the holder drop series is offered by the close agreement with the theoretically straight line relation, Fig. 2, of all the points representing total gas per hour at various test loads. Although each test lasted but a few minutes, from 8 to 11, yet the determination of the rate of fall by this method is fully as accurate as for the fall of a holder of twice the capacity observed for a period twice as long.

52 Furthermore, the effect of any possible error in reading the tape is certainly negligible. Thus assuming an error of one inch, in

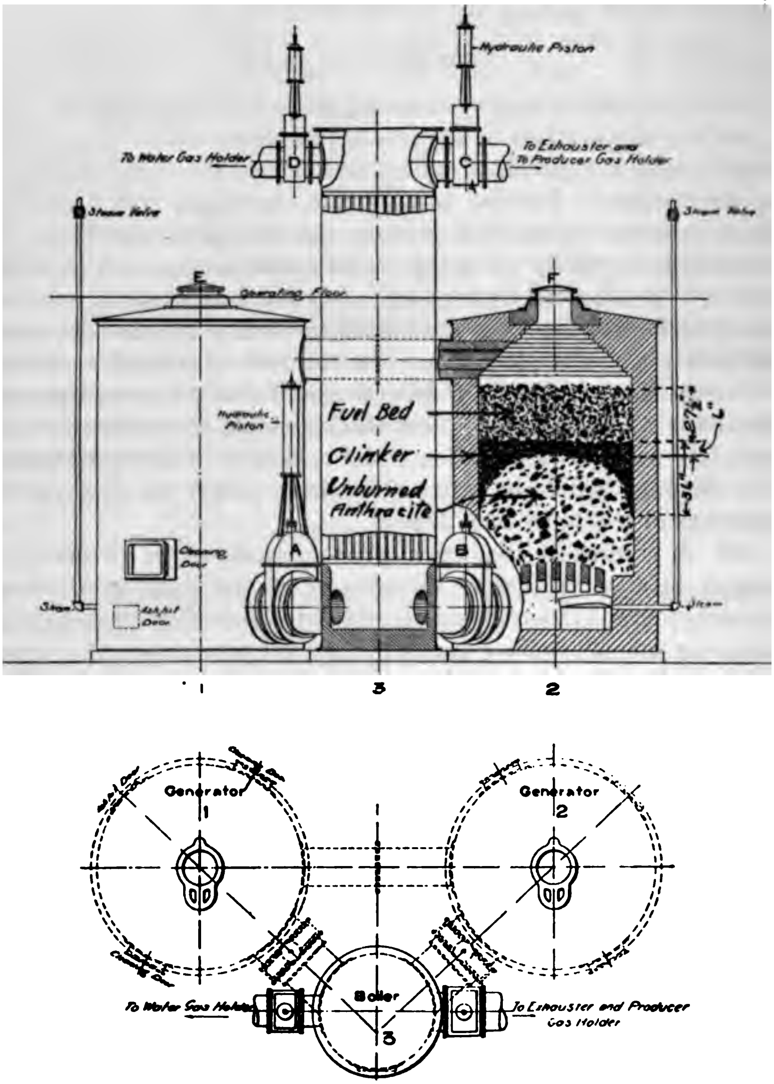

FIG. 12 SKETCH OF PRODUCERS AND FUEL BED AFTER 59 HOURS RUN

the measurement, which is entirely out of the question, if analyzed graphically as above, this would represent but 1 per cent of the gas consumption at full load, as the total fall corresponding was about 100 inches. Another point to be considered is that leakage in gas during the holder drop runs, due to lack of tightness of valves in the producer house, results in more gas being charged to the engine than used, as the leakage from the main which is under pressure would escape to the purge stack through the leaky valves.

OIL CONSUMPTION

53 Owing to the continuous circulating filtering system in use at the plant, no perceptible amount of engine oil was used during the test, all the drains from the journals being returned to the supply system. At the beginning of the test cylinder oil pumps were filled, and the level noted on gage glasses. At the end of the test, they were filled to the same level by a measured quantity of oil, which showed the entire quantity used.

DUST DETERMINATION

54 Samples of gas, delivered to the engine, and from wet scrubber, were examined for dust. For this purpose, a tube containing loose cotton was used, the weight of which was determined before and after the passing of a measured quantity of gas (five cubic feet), the difference being the accumulation of impurities. This tube was heated before and after to drive off moisture.

COAL SAMPLING

55 From each 1200 pound batch of coal weighed out at intervals of about two hours, a sample of about 100 pounds was quartered down and preserved in a glass can. Similarly, a sample of the anthracite from which the new producer fire was originally started was preserved. When the fires were drawn at the end of the test extreme care was taken to obtain a fair sample of the so called "ash" removed from beneath the clinker zone. Three separate samples were taken and quartered down from a full barrow. A Parr calorimeter was used for the determination of heat values.

COAL CONSUMPTION

56 In regard to the precise method of conducting producer gas tests of this kind, involving coal consumption, opinions seem to

differ widely, particularly as to the method of assigning "debits" and "credits" for varying conditions of fuel bed before and after the test. It was the original idea to equate the conditions as far as possible at the beginning and end of the test, as would be the case in testing a continuous type producer; that is, to make a "flying start" and end in a similar manner, so that the actual amount of coal fired would be the correct amount chargeable to the test. But with the present practice of week-end cleanings of the producer fires employed in the intermittent type of plant, the test was necessarily started with producers practically full of "green" fuel, largely anthracite, with a topping of bituminous.

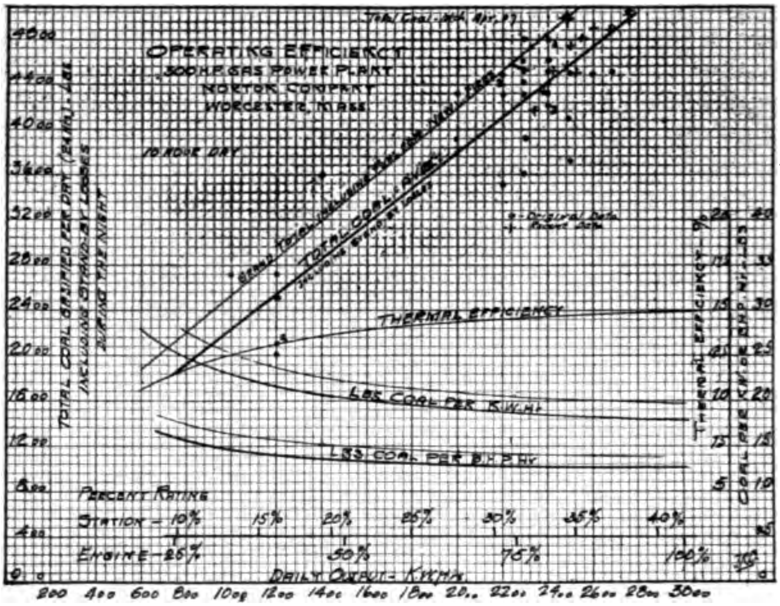

FIG. 13 OPERATING EFFICIENCY 500 H. P. GAS POWER PLANT

57 At the end of the test, midnight Wednesday, it was expected that this original fuel bed had depreciated in value, but when the fires were partly cleaned on the next night, Thursday, the majority of this anthracite was found still in the producer in the form of good combustible of practically the *same* heat value as the original anthracite. Analyses of this "ash" are given in Table 5. These analyses showed 10 per cent higher carbon content than the original coal. The obvious inference is that the anthracite bed operated as a filter for the bituminous bed above, from which carbon was

actually deposited rather than dissipated during the descent of the hydro-carbon gases.

58 A careful survey of the fuel bed Wednesday night, immediately after the close of the test, showed conditions approximated by Fig. 13, which applied to both producers. The upper "ash" (clinker line) was found definitely located, practically flat and at the same level in both producers on the average 27½ inches below the top of the fire. The original anthracite bed had shrunk about 25 per cent in volume and 40 per cent in weight.

59 Assuming now that a fuel correction is necessary, if the test is to be charged with all of the coal originally fired, it must also be credited with the combustible remaining in the producer at the close of the test. To this end it is assumed that the 27½ inches of fire bed varies uniformly in combustible from fresh "green" coal at the top, to ash at the bottom; that is, it is equivalent to half of good fresh coal of full heat value. This refers only to that part of the bed lying above the clinker line. Crediting the test with this salvage

TABLE NO. 8 NORMAL OPERATING ECONOMY

NORTON GAS POWER PLANT

AVERAGE FOR NINE WEEKS ENDING APRIL 21, 1907

Number of hours per week run on load	54.4	hours.
Output	13 500.0	kw-hrs.
Average running load	248.1	kw.
Average running load per cent rating of engine	72.2	per cent
Coal gasified (including standby losses)	24 839.0	pounds
Coal for new fires	2 369.0	pounds
Coal for new fires (per cent of producer coal)	9.5	per cent
Total coal for all purposes	27 204.0	pounds
Avg. total coal per hour including new fires	500.00	pounds
Coal consumed (excluding new fires) per kw-hr	1.83	pounds
Total coal consumed per kw	2.015	pounds

value of the remaining fuel bed, and the proper thermal shrinkage in the anthracite originally fired, the net charge works out to a debit against the test of 998 pounds of bituminous coal which may be considered as a correction to the amount actually fired. This results in a coal consumption for the entire plant of 1.006 pounds per brake horse power hour, as compared to 0.965 pounds per brake horse power hour based upon the coal actually fired, and a producer efficiency of 70.87 per cent.

60 It will be noted from the above that the point at issue involves a comparatively small correction. Even admitting an error of 25 per cent in the valuation of the remaining fuel bed, the resulting

error is but 1.85 per cent of the total, which is inconsiderable under the circumstances. Two factors, however, tend to justify discarding this correction: first, that the producer was not "starved" of fuel toward the end of the test in fact, quite the contrary, as is shown by the log, Fig. 3; second, that as fuel was fired in small quantities every five or ten minutes no appreciable error in the weight actually charged would be incurred either the one way or the other.

61 That the actual results recorded in this paper are quite reasonable is clearly demonstrated by the results that are being obtained in the normal operation of the plant, shown in Table 8, which summarizes a period of nine weeks ending April 21, 1907. While the average load was but 72 per cent of the engine rating, the coal consumed during the week, including 14 hours daily standby loss, averaged but 1.83 pounds per kilowatt hour, or, including the fuel required for rebuilding fires on Sunday, 2 pounds per kilowatt hour. In Fig. 14 these operating data are analyzed for various loadings occurring during the period covered. From this it appears that the plant would require 1.78 pounds per kilowatt hour during weekly operation, out of which the plant is idle nearly three-fifths of the time. This agrees closely with the results of the Gould Coupler gas power plant, presented before the Society in December, 1906.

PERSONNEL OF TEST

THE NORTON CO.

Mr. Geo. I. Alden, director.
Mr. D. L. Gallup, assisting.
Mr. Daniel Armistead, general charge of observers.
Mr. J. R. Bibbins, general charge of test.

OPERATION.	DAY	NIGHT
Indicator 1	Mr. Bibbins	Mr. Day.
Indicator 2	Mr. Bradley	Mr. Day.
Indicator 3	Mr. Hill	Mr. Leland.
Indicator 4	Mr. Bisson	Mr. Dodge.
Switchboard	Mr. Mudgett	Mr. Stevenson.
Calorimeter	Mr. Phelps	Mr. Burke.
Analyses	Mr. Von Sholly	Mr. Griffin.
Coal	Mr. Keith	Mr. Johnson.
Water Consumption	Mr. Bibbins	Mr. Day.
Temperatures and Pressures	Mr. Armistead	Mr. Day.

General Assistant................Mr. Chapman.
General Assistant................Mr. Morden.

Calibration of electrical instruments........Messrs. Fick and Mudgett.
Holder drop, pressure and temperature.....Messrs. Bibbins and Day.
Producer fires and ash sampling...........Mr. Bibbins.
Computations and indicator cards..........Messrs. Armistead, Bibbins and Day.

Norton Company.........................Messrs. Alden and Griffin.
Worcester Polytechnic Inst...............Mr. D. L. Gallup.
Amer. Steel and Wire Co..................Messrs. Hill, Bisson, Burke, Leland, Stevenson and Phelps.
Power and Mining Machinery Co...........Mr. Von Sholly, chemist.
The Westinghouse Mch. Co...............Messrs. Armistead, Bibbins, Chapman, Bradley, Dodge and Day.
W. E. & M. Co...........................Messrs. Fick and Mudgett.
General.................................Messrs. Keith, Johnson and Morden.

DISCUSSION

MR. W. H. BLAUVELT Mr Bibbins referred to the fact that a variation in the calorific value of the gas makes but a relatively small variation in the power developed by the gas when exploded in the cylinder, owing to the large dilution by the air necessary for combustion. The Society may be interested in some experiments made at the Massachusetts Institute of Technology to determine the percentages of air required for admixture with different gases to produce the best explosive mixtures. These experiments show that in the case of water-gas the best efficiency results when using that quantity of air which gives a theoretical maximum pressure of about 125 pounds per square inch. Using this quantity of air for the different gases (except blast furnace gas), we have the following table which shows the volumes of air per one volume of gás, and the percentage of hydrogen in the mixture of air and gas as exploded:

	Anthracite producer gas	Mond producer gas	Coke oven gas	Blast furnace gas	Natural gas
Volume of air per one volume of gas.......	1.09	1.50	8.93	0.65	12.40
Per cent of hydrogen..	7.77	8.16	4.60	0.00	1.50

2 From these last figures it is plain that the claim made by some that coke oven gas is more liable to back firing, or preignition, on account of its high percentage of hydrogen, can hardly be maintained, since the percentage of hydrogen is lower in the mixture as exploded than either anthracite or Mond producer gas.

Prof. Wm. Kent Mr. Bibbins states that this test was a service test, and not primarily for efficiency.

2 I should like Mr. Bibbins to explain in what way the performance could have been bettered. He did say something about the temperature of the jacket water and that if it had been hotter the efficiency would have been higher. I should like to have him elaborate this point and also to say what other changes would have tended to increase the efficiency. You couldn't change the size of the engine; nor the speed; nor the composition of the gas. It seems to me there was very little that could have been changed, The record of the test is very valuable and I am glad to have it, but there is one little thing to which I would like to take exception.

3 In Par. 4 the author says that the engine used perhaps one-third of the coal that would have been required for steam power. Now I notice that the gas engine used 0.805 pounds coal per one horse power hour. Three times that consumption would have been 2.415 which would be the rate for a very uneconomical steam engine, and more than double the figure for the best practice. The gas men compare the gas engine with the old style steam engines. Why do they not compare it with performances of triple expansion pumping engines, which have reached a consumption of 1.05 pounds on Clearfield or Pocahontas coal, and in which there is a possibility of getting down to ninth-tenths of a pound? That is a figure which can be reached by a steam engine; why use the steam figures from an old worn out plant 20 years old?

Prof. C. E. Lucke The average member who has not tried to make a producer gas power plant test does not realize the difficulty of the job, and I hope that the discussion of Mr. Bibbins' paper will not degenerate into little quibbles in regard to the details of this test.

2 I think, on the whole, we are to be congratulated on getting results that are so clear and definite. There is a question I would like to have answered, concerning the peculiar behavior of the anthracite and bituminous coal in the producer, both being present at the same time. As I understand it, the bituminous coal, in gasifying during the distillation stage, carries down carbon in the volatile form to the anthracite bed and there deposits some of it.

3 If this is the case, there is a very important principle involved because certain forms of carbon gasify in producers more rapidly than others. For instance, a porous variety such as we have in charcoal, gasifies at low temperatures and rapidly, whereas carbon, in the lamp black or soot form, requires high temperature and a

longer time of contact between the air or CO_2 and the carbon to effect gasification. If it is true that some of the bituminous carbon is deposited in the form of soot, on the anthracite, it would appear that because higher temperature is required to gasify it and the deposit was made at a point where the temperature was quite low, it might never be regasified. I ask Mr. Bibbins if he can throw some light on this phenomenon of transfer and redeposit of carbon.

PROF. SIDNEY A. REEVE In Fig. 8 is shown a curve of producer efficiency, rising with an increase of load. I would inquire how this curve is obtained, since no observations of fuel consumption could be associated with the holder drop tests.

2 Secondly, if this curve be true, does it not show that the producer capacity was too great for the engine rating? At the maximum load recorded, an overload of 20 per cent, the producer efficiency is still rising rapidly. We naturally expect of gas producers the same general form of characteristic shown by all other devices (except the Otto type of gas engine), viz: a region of maximum efficiency at or slightly below rated load, with decreasing efficiency under overload. Undoubtedly this producer would develop such a characteristic were it pushed sufficiently. But from the diagram it does not appear to have approached its point of maximum efficiency, even at 600 horse power.

3 In Par. 29 I notice discussion of the possible effect upon the hydrogen content of the gas of varying the period of water gas making. As this period is stated as amounting to only 20 or 30 seconds—occurring how often is not stated—it must be a matter of considerable moment in the efficiency of operation to end this period correctly.

4 Mr. Bibbins in describing the holder drop tests, speaks of the avoidance of variation in holder dimension by sun heat, by making the tests at night. Is not the effect of temperature upon the accuracy of such readings much more noticeable in the temperature of the gas than in the temperature of the shell? I would inquire what measures were taken to determine the temperatures of the gas at different points in the holder, and at different times.

5 I am interested in the form of characteristic of engine efficiency shown in Fig. 2, as corroborating, by the latest accepted practice, the statements made in my own paper of the present session, viz: that it is a fundamental characteristic of the best existing gas engines that the efficiency should become a maximum only at maximum overload. Mr. Bibbins' engine shows a maximum efficiency of over

25 per cent, but only at 14 per cent overload; the maximum, apparently, of which the engine is capable. If it be assumed that in usual practice an engine load will vary between 60 and 100 per cent of rating, or between 50 and 115 per cent, then the average efficiency of this engine would be less than 23 per cent, or an eighth less than the best of which it is actually capable. The misfortune of this fact, however, does not lie so much in the loss of coal involved as it does in the inadaptability of the gas engine to meet heavy overloads with a wide margin of power.

Prof. L. P. Breckenridge I should like to submit the following figures representing some recent steam turbine performances. The turbines are installed in a large Chicago power plant.

a Turbine installed four years ago, 4000 kilowatt capacity, gave a steam consumption of 23 pounds per kilowatt-hour.

b Turbine installed two years ago, 4000 kilowatt capacity, gave a steam consumption of 17 pounds per kilowatt-hour.

c Turbine installed one year ago, 9000 kilowatt capacity, gave a steam consumption of 12.93 pounds per kilowatt-hour.

Mr. R. E. Mathot It has often been demonstrated that the output of a steam engine apparently does not affect its internal friction load.

2 The most accurate method of determining the mechanical efficiency of a steam engine consists in taking the indicator diagram and calculating the power of the engine at zero load and then at normal load. The mechanical efficiency will then be expressed by the ratio of the difference between these powers to the power at normal load.

3 I have never succeeded in ascertaining exactly the mechanical efficiency in the way Mr. Bibbins reports in his paper, that is, by comparing the effective power recorded by the brake with the power calculated from the corresponding indicator card.

4 The accuracy of an indicator cannot be depended upon in recording full load on an explosive engine, for there are too many sources of error, as pointed out by Professor Lucke, besides many mechanical troubles in the operation of the indicators. The only practical way of determining the mechanical efficiency seems to be the method used in testing steam engines.

5 A light or weak spring should be used for a series of at least 30 to 50 cards, when the engine is under no load. This operation should

be repeated several times with springs of different scales, so as to check one spring by the others and they should all be calibrated for errors.

6 The indicated power so recorded would be the effective horse power required by the engine itself to overcome its own internal friction and resistance and give a means of calculating mechanical efficiency.

MR. C. L. STRAUB[1] I notice that Mr. Bibbins refers to the efficiency of the producer, based on the lower heat value of the gas. This is not a true efficiency of the producer. The efficiency of any apparatus, whether a gas producer, steam boiler, or other device, is computed in terms of the actual value of the output energy, divided by the actual value of the input energy, the result being the percentage of the efficiency.

2 The actual output value of a gas producer is represented in the higher heating value of the gas, it being no fault of the producer that the gas engine is unable to cope with the latent heat of steam, due to the combustion of hydrogen in producer gas. When reference is made to the efficiency of any gas producer, it should in justice be made to the higher heating value of the gas furnished by that producer.

3 I would also like to ask Mr. Bibbins whether, in calculating his efficiencies, he used as his fuel basis the lower heat value of the fuel, and whether the calorific value of the fuel was determined by analysis or by calorimeter. If by the former method, unless commensurate allowance was made, a high heating value was obtained. It is a fact also, that the calorific value of any fuel as determined by a bomb-calorimeter, should be referred to the lower heating value of that fuel, providing the gas produced from the fuel is also referred to the lower heating value of the gas.

4 Information was asked regarding the depreciation on gas engines and gas power plants. I know of a number of gas producer plants that have been in operation for 20 years and are still running. In one plant at New Haven, Conn., the average repairs per annum for seven years, have been $147. This plant was installed to burn under normal conditions, about 18 lb. of fuel per square foot of combustion area. This is at the rating of 1000 h.p. on each pair of the four units. Under their commercial conditions, they are burning considerably over forty pounds of fuel per square foot. This means that they are getting continuously over 100 per cent overload out of the producer,

[1] Engineer, Loomis, Pettibone Company, New York.

and their efficiencies are considerably over 80 per cent, based on the lower value of the gas.

Mr. Bibbins is to be complimented upon the very interesting paper he has presented.

PROF. WILLIAM D. ENNIS. The thermal efficiency curve of Fig. 2 is important, and should be thoroughly established. In the

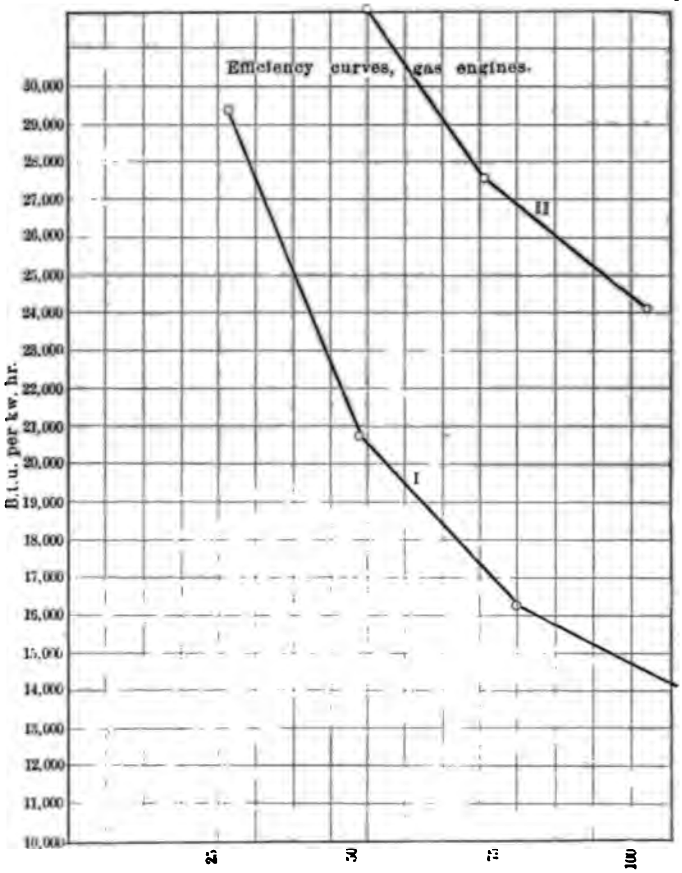

FIG. 1 CURVES SHOWING GAS EFFICIENCY

accompanying diagram, Fig. 1, curve *I* is plotted from the data given in Table 1. Curve *II* represents the results of three trials made in August on a 500 h.p. Westinghouse horizontal double acting gas engine with a 300 kw. direct current generator and a gas generating unit built by R. D. Wood & Co., located at Richmond. This curve shows a less economical performance than the former, but the light load efficiency is higher in proportion to the full load efficiency. In other words, the curve is less steep. The results charted are those of actual operation, the three tests being of from 125 to 136 hours duration on actual shop loads so that the results are comparable rather with that given in Table 8, viz: 2.015 pounds coal consumed per kilowatt hour, than with the brief "holder drop" tests of Table 1, or the 51 hour test. The best result at Richmond was 1.653 lb. of Pocahontas coal per kilowatt hour, on a fluctuating load which averaged slightly over the generator capacity. The efficiency from coal as fired, to bus-bars, was about 14 per cent. This may be compared with the figure of 10.3 per cent recently given for one of the largest and most economical of our steam power plants. The thermal efficiency of the engine was close to 25 per cent.

2 There is nothing gained by comparing these curves with those of steam engines. As is pointed out in the paper the total hourly fuel consumption, Fig. 2, is represented by a nearly straight line. Without mechanical losses, the efficiency curves of the accompanying diagram would be nearly horizontal lines. The greater preponderance of the effect of mechanical losses at light loads gives these curves their inclination and curvature. We might select for comparison a steam engine having very low mechanical losses—a simple engine. It would give a better efficiency curve, of course; but if we selected a more economical type of steam engine, the mechanical losses would be higher and the efficiency curve would not be as good as that of these two gas engines; still it would on the whole, be more efficient than the simple engine. As far as thermal efficiency is concerned, the total hourly fuel consumption, charted as a nearly straight line in Fig. 2, shows it to be almost constant; in the Richmond tests it was still more nearly constant. In order that such gas engines may have efficiency curves equal to those of the best steam engines, it is therefore necessary only that the mechanical losses be as low. Mechanical efficiencies of 83 per cent, as given in *f*, Par. 3, certainly give no ground for apprehension in this respect.

MR. W. H. MORSE I have been rather interested in the statement of Mr. Straub as to the rate of combustion per square foot as compared with his test. This test ranged from about 12½ to 17 lb., and if I am not misinformed, the horse power rating of this producer was about the same as that of the engine. I should like to know whether there were any indications during this test that the producers were operated close to their maximum rating.

2 How close to its rating (designed efficiency) did the producer

operate? I have no information on this, excepting from the owners of the Norton plant, and I feel quite safe in saying that we could by no means have carried a full consumption rate, as the difficulties in carrying the heats of the fires would, in my judgment, have been insurmountable especially in continuing the test for 151 hours, which corresponds to a full week's practical run.

THE AUTHOR Professor Reeve inquires why the producer efficiency curve is not flatter at full load. The characteristic curve of producer efficiency involves, as explained in Par. 26, an assumption that the losses in the producer bear a certain relation to the weight of coal fed into it; i.e., to the heat input. Our assumption, however, covers a comparatively short range of load, 400 to 550 b.h.p., so that no great error was involved in considering the two lines representing producer and engine input as parallel. Owing to the difficulty of running a sufficient number of coal consumption tests, we have no actual knowledge of the characteristic curve of producer efficiency.

2 Supplementary note: Since the original calculations upon producer efficiency were made, a new method of obtaining a fairly accurate knowledge of the producer efficiency at fractional loads has occurred to me. This is outlined below. In the average producer plant, it is usually a difficult matter to conduct tests of the necessary duration at fractional loads. The only alternative that seems to meet the necessities of the case is to determine the average coal consumption during several periods in which the plant is kept running idle; and again, through standby periods, as, for instance, during Sunday in a plant not operating continuously. With a number of such runs averaged, fairly accurate data representing producer input at fractional loads, would be available. These may be applied as follows:

3 Referring to the accompanying curves, Fig. 1, the plot is identical with that of Fig. 8 in the paper, with the exception that the area at the left of the origin has been included. The line of engine input is re-plotted from Fig. 2. As it is based upon a number of tests at different loads, we may assume that a proportional relation exists between load and heat input to the engine. Producing this line to the left, indicates that the losses (area A) inherent to the engine-driven unit, are 166 kw., covering mechanical friction, windage and all thermal and electrical losses up to the point of useful power generation.

4 But even with the engine standing idle, a certain loss is incurred in keeping the producer fuel bed up to the gasing point. Locate

above this secondary origin a point B representing the heat value of this standby coal.[1] Locate also a point N representing the heat input during the 51-hr. coal consumption test. We now have two points, B and N, with which to locate the line of producer input throughout the entire range of load. Producing this line to the left, indicates that the standby loss (area C) is equivalent to 70 kw., which is less than one-half of the no-load engine loss.

5 Total area D, or conversely, the rectangular area E at the right of the primary origin, now represents the total loss between coal pile and switchboard, which remains constant at all loads and may be considered as an overhead, or fixed charge upon the plant.

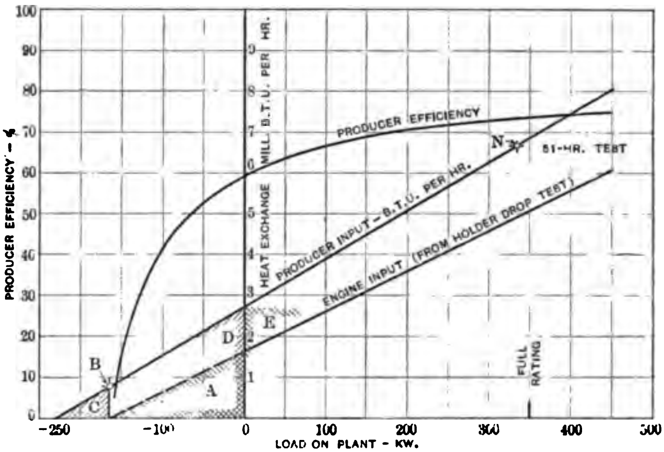

FIG. 1 METHOD OF ESTIMATING FRACTIONAL PRODUCER EFFICIENCIES

Without this loss, it follows that the producer plant is capable of delivering power at the rate of 0.8 lb. per kw-hr. net at any load within its range of capacity; or in other words, its efficiency is constant.

6 From these two lines, the producer and engine input respectively, the producer efficiency curve may be obtained. At full-load, the efficiency is approximately 75 per cent, at half-load, 70 per cent, at no-load, 60 per cent—something of a paradox, as one naturally

[1]At a 500 h.p. producer gas plant at Richmond, Va., this standby coal consumption averaged 46 lb. per hour. At the Norton plant, the standby loss is somewhat higher owing to the extra loss incurred in rebuilding fires weekly. On the whole, however, the two different types of producers agree extraordinarily in this respect.

expects efficiencies to fall off progressively from maximum at full-load to zero at no-load. But it is interesting to note here that at no-load on the plant, the producer operated at a rate of practically one-third its normal output at full-load.

7 This efficiency curve is slightly flatter than that assumed in the paper, as embodied in Fig. 8; but, on the other hand, it seems to bear out in general the assumption made. The fact that the producer and engine input lines are not exactly parallel, indicates, first, a certain constant loss at all loads combined with, second, a variable loss increasing with the load, due perhaps to the increased loss of sensible heat in the gas, etc.

8 This cursory study indicates that the gas producer throughout the range of operation in the average plant is not only an unusually efficient piece of apparatus, but its efficiency is little affected by varying loadings. How best to conduct tests on this type of apparatus, is a matter for future consideration; but it is fortunate that the standby loss, both with the engine running and idle can be determined very simply, only one observation being involved, viz: the weight of coal, and an average of several runs should give accurate results.

9 Professor Reeve predicts a drooping efficiency curve, were the producer pushed hard enough. This seems to be a rather fictitious case, inasmuch as the operative difficulties surrounding any attempt to run at higher rates of gasification would prevent this point being determined—at least, such would have been the experience at Norton unless special equipment were provided.

10 Regarding the effect of temperature on gas readings: Unquestionably the temperature variation of the gas is much more important than that of the holder shell as effected by sun heat. Nevertheless, to avoid one possible source of error, the tests were run at night. As all measurements of gas quantity were made at the holder, a careful record of the pressure and temperature was made by the apparatus shown in Fig. 11 (paper), located at the holder outlet. By lifting the thermometer through the central tube provided, allowing gas to escape through the tube with considerable velocity, an accurate measure of the gas temperature was obtained. This varied but a few degrees throughout the test.

11 The frequency of water gas making for the entire test is shown by the gas log, Fig. 4, the time of each water gas run being plotted in per cent of the corresponding interval of air gas run. These runs were maintained fairly constant, and the respective periods seem to be dependent largely upon the condition of the fuel bed and the character of gas desired. With too long runs on water gas, the fires would

be killed and steam would pass through without disassociation; with too short runs, the high temperature of the fuel bed would bring about excessive clinker formation. Some plants, requiring the maximum make of water gas, blast the fires for a shorter period, but at a much more rapid rate, thus keeping down the average temperature while increasing the output.

12 Mr. W. D. Ennis refers to efficiency tests conducted at Richmond upon a producer gas power plant of the same size and character, except equipped with a different type of producer. The principal reason for the somewhat lower efficiency shown is that the Richmond test was run at a considerably lower load than the average for the Norton test, even though above the generator rating. Consequently the curves, 1 and 2 in Fig. 1, accompanying his discussion, are not strictly comparable. Owing to the wide difference of opinion as to desirable over-load capacity of gas engine, the generators in this particular plant were much smaller than the corresponding load capacity of the gas engines for continuous running. The Richmond test curve No. 2 should more properly be compared with Fig. 13 in the Norton paper, representing a large number of weekly operating results averaged graphically. These show about 1.8 lb. net coal per kw-hr. at a load corresponding to the Richmond test, which result checks fairly well with the latter when it is considered that the Norton plant runs but little over 30 per cent of the time with the 14-hr. standby losses included in these economies. By plotting the three tests at Richmond for various loads, the coal consumption of the plant at full engine load may be obtained by exterpolation, 1.59 lb. per kw-hr., equivalent to a little under 1.0 lb. per brake horse power hour.

13 Professor Kent deprecates the comparison of gas plant with what we may term the average steam plant. He cites some very high steam efficiencies and inquires how our efficiencies at Norton could have been improved. Perhaps we have made the comparison too abrupt, but I may again mention the fact that the Norton plant was tested in its regular everyday working condition, and as such, is comparable with the average operating results from a high grade Corliss plant. The general practice in steam engineering to base efficiencies on indicated horse power makes it more difficult to appreciate offhand the greatly improved efficiencies obtained from a good gas engine in which power is usually measured by brake or electrical horse power.

14 The Norton test results might have been improved in many ways entirely aside from the special care usually put upon an equipment to insure that it may be perfectly attuned to the requirements of the test. A steady rheostat load might have been substituted for

the variable shop load occurring during the day, yielding a higher average load than recorded. The temperature of the jacket water might have been raised considerably, thereby decreasing the jacket absorption by a considerable percentage, part of which would be realized in increased engine efficiency. The producer fires might have been worked over continually to maintain more uniform conditions and better gas. Although the difference is not material, the engine will respond to an improvement in quality of gas, its capacity increasing with the heat value of the mixture. Take for instance the case of natural gas versus blast furnace gas, a large difference exists—perhaps as much as 30 per cent—in the heat value of a cubic foot of respective mixtures. Although the higher compression of the lean gas compensates to some extent, the latter evidently necessitates a larger cylinder for the same capacity, and hence a somewhat higher engine friction. And this is entirely independent of the question of combustion within the engine cylinder. Any considerable variation in gas quality requires an adjustment of mixture at the engine. Hence, it is an unquestionable fact that to produce the best efficiency of combustion, the quality of gas must not be allowed to vary as it did to some extent during the Norton test (from 101 to 126 B.t.u. per cubic foot). It is, therefore, quite reasonable to predict an even higher plant efficiency than here recorded with the proper conditions maintained.

15 I appreciate the sympathy extended by Dr. Lucke in his comments upon the difficulties surrounding the testing of a producer of the intermittent type, and I am free to confess my total inability to analyze further, with the data at hand, the curious phenomenon of carbon deposition, which apparently took place within the producer. To my knowledge such a producer reaction has not been reported before; at least I have never noted any comments upon it from other investigators.

16 Mr. R. E. Mathot's method of computing mechanical efficiency does not seem to me applicable to a test of this nature. In fact, the efficiencies based upon the difference between full load and no load power, as constant loss would involve a very serious error in that the same conditions as regards either friction or combustion efficiency, do not obtain at full load. With increasing load, the engine friction unquestionably increases, due to the heavier bearing and pin pressures and thrust of piston rings against the cylinder walls. The former has been demonstrated by tests of large steam engines (e.g., 6500 h.p. vertical, three-cylinder Corliss, New York Edison, Waterside Station) and it should be equally true in the gas engine. The accuracy of the graphical method, in Fig. 5 of the paper, entirely avoids this assump-

tion of constant engine friction, whether right or wrong. And its accuracy is proved by the almost perfect agreement of the two 10 hr. average points covering periods of fairly constant load which were plotted after the average line was drawn. This method is practically equivalent to calibrating the generating unit.

17 As to the accuracy of the indicator for gas engine work, I would emphasize the fact that with a slow-speed engine, such as we are dealing with, most of the difficulties of high speed work are avoided, and with reasonable care in the calibration of springs and in keeping the indicator clean and well lubricated, the most serious errors at least are overcome. From a detailed inspection of these 72 sets of cards, we feel reasonably sure of an accurate result; especially when the erratic results may so easily be detected, as by the graphical method.

18 As to the highest temperature that can be permitted for discharge jacket water inquired into by Mr. Parker, the average during the test held close to 110 deg. fahr. Individual water circuits, however, may have run higher, although we did not attempt to observe other than the total discharge from the engine. This represents normal practice at this plant, but the jackets might have run much higher, probably 150 deg. fahr. Some gas engine plants are operating on even hotter jacket water—one discharging at about 200 deg. fahr. in connection with a cooling pond; but 150 deg. may be considered a reasonable limit.

19 In reply to what Mr. Morse has said as to the probable maximum rate of combustion with the Norton equipment, I feel quite safe in saying that we could not have carried a much higher rate than the maximum during the test, 17 lb., unless this could have been brought about by operating the producer differently, and no experiments were made along this line. Certainly double the combustion rate would have been out of the question, considering the conditions obtaining after the 58 hr. continuous run, which corresponds to over a full week's commercial run.

20 Mr. Straub raises the vexed question of higher versus lower heat value of gases. This is an involved subject and one upon which a wide difference of opinion seems to exist. However, the analogy he introduces concerning the use of higher or lower heat value in fuel determinations, is, to my mind, hardly effective in influencing the argument one way or the other for the heat value of gases. At best, the difference is small as compared with gases in which there may be from 10 to 15 per cent difference between higher and lower values. The subject seems to me too complex to discuss adequately in this

connection, and I can best refer to a communication from Mr. Arthur J. Frith in the discussion of the standardization of engine tests, Transactions, vol. 24. His discussion is brief and masterly, and I wish to add only one thought. Assuming the gas engine to be a non-condensible vapor engine, it is reasonable to stipulate that it should be supplied with a gas suitable for its use. Should, therefore, the engine be held responsible for wide and sudden fluctuations in the hydrogen content of gases? Is its efficiency as a heat transforming mechanism subject to sudden change, whenever the hydrogen content changes from one cause or another? Mr. Frith even raises the question of the application of the term "efficiency" to fuel gas; e.g., 100 per cent efficiency for a gas containing no hydrogen; and the efficiency decreasing as the hydrogen content increases.

No. 1167

CONTROL OF INTERNAL COMBUSTION IN GAS ENGINES

By PROFESSOR CHARLES EDWARD LUCKE, NEW YORK
Member of the Society

One of the primary prerequisites for close engine control or regulation, be that engine a steam engine, a gas engine or any other kind of motor, is absolute constancy of cyclic effort with a fixed position of the controlling mechanism. The promptness with which a change of effort will follow a change of setting of the governing or regulating gear depends among other things upon the cycle of operations to be carried out in the cylinder, and, in the case of gas engines, the cycle is such that much time may elapse between a governor movement and the controlling effect desired. This has been clearly pointed out in many papers and as ordinarily called "cyclic influence" it is well understood. It is the object of this paper to examine into the conditions under which constancy of effort may or may not be obtained with constancy of setting of the governor and valve gear.

2 It is possible in gas engines to get many different indicator cards at apparently constant external load, the differences indicating differences of effort and in most gas engines, even with the mechanism for controlling the engine fixed in position, the same variation of indicated effect may be observed. The differences which will appear on the indicator card for apparently identical conditions are not differences in compression, suction or exhaust lines, but almost entirely differences of combustion and expansion lines, or as the expansion line position is fixed by the combustion line, it may be said that the differences are due entirely to variations in combustion lines.

3 It would appear, therefore, that because combustion lines in gas engines are not identical for apparently identical conditions of the mechanism that we have failed to control this combustion in a man-

Presented at the New York Meeting (December 1907) of The American Society of Mechanical Engineers and forming part of Volume 29 of the Transactions.

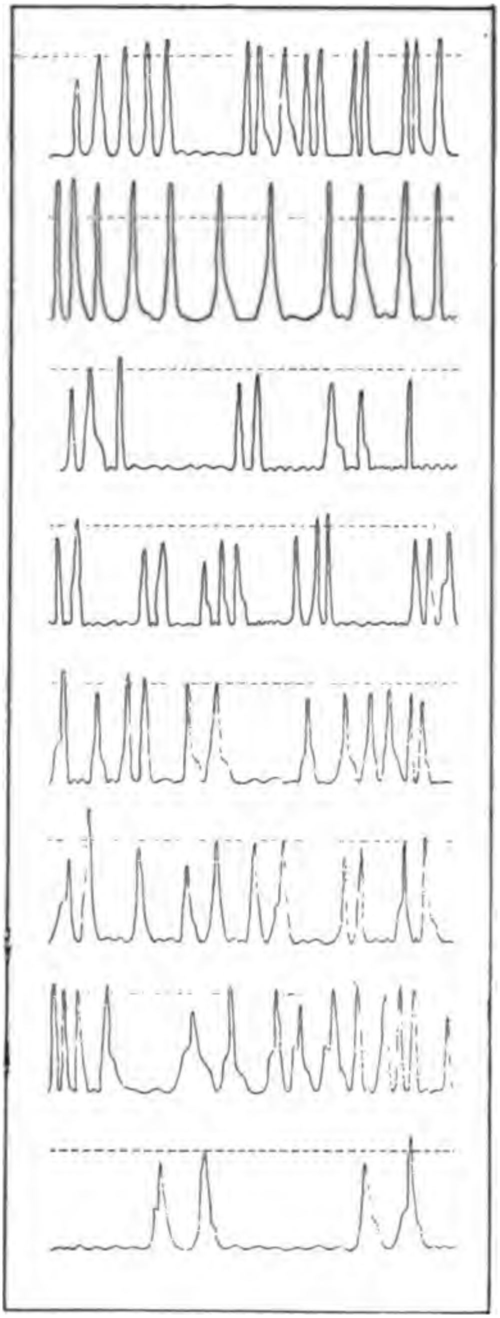

FIG. 1 CONTINUOUS RECORD SHOWING VARIABLE MAXIMUM PRESSURES

ner required by everyday practice in the use and application of gas engines. Whether, however, this failure is due to ignorance on the part of designers, or whether the end sought is in opposition to natural phenomena, will not appear without analysis.

4 As an illustration of some of these variations Fig. 1 is presented and represents a continuous record of the maximum pressure over several strokes in a small gasolene engine governing by holding the exhaust valve open when the load is light, each line giving the results of one constant adjustment. Aside from the variations produced by the idle strokes, which are, of course, not here considered, it is to be noted that the maximum pressures for any one adjustment

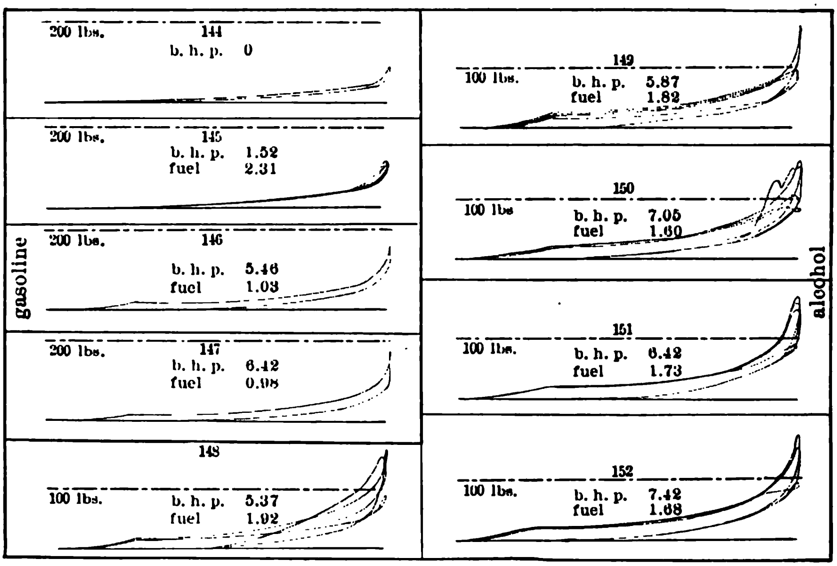

FIG. 2 INDICATOR CARDS SHOWING PRE-IGNITION

which should be identical are not identical, and that in some cases they are more nearly identical than in others.

5 From the set of indicator cards of Fig. 2 it appears that the ignition is sometimes spontaneous or starts from some point on the compression line before the ignitor has acted, indicating preignition of the charge. A still different sort of variation or lack of constancy is shown in Fig. 3; the variations are those due to height of combustion lines and the form of that part of the combustion line which runs into the expansion line. In Fig. 4 there is presented another indicator card in which not only is there a variation of the combustion line

similar to that of Fig. 3, but one of another sort; a violent wave appears at times, different for successive strokes and sometimes absent.

6 An examination of the indicator cards here presented and many others of a similar kind that every gas engine experimenter has found at some time or other will indicate that the variations in

FIG. 3 VARIATIONS OF COMBUSTION LINES

the combustion line are principally of three sorts, running one into the other; first, there may be too early a beginning of the combustion line or preignition, which comes and goes sometimes in the most puzzling fashion, but which at other times can be traced to a removable cause and eliminated; secondly, with an absolutely constant ignition and smooth lines successive strokes may indicate a displacement

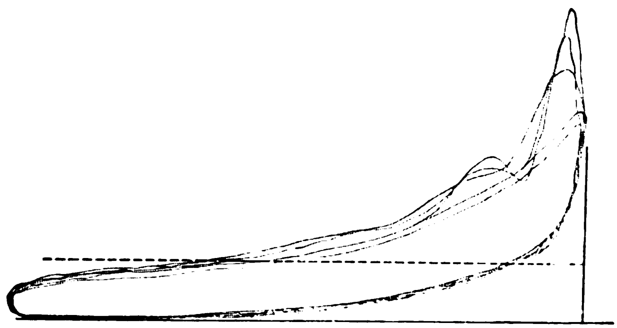

FIG. 4 VARIATIONS OF COMBUSTION LINES WITH WAVES

of whole or part of the combustion line. This is a mixture variation effect. Thirdly, there may be at some time violent waves or even mild waves differing on successive strokes, passing away and recurring at times, and at other times persistently present. This is the phenomenon of the explosive wave.

MIXTURE EFFECTS

7 A variation of mixture may affect the combustion line through a change in the rate of propagation, which results from changes in mixture proportion considered in conjunction with piston speed. A slow burning mixture will tend to give a flatter combustion line with a fixed piston speed than a fast mixture. Likewise, a mixture may begin to burn rapidly and finish slowly, giving succeeding combustion lines which coincide in part, but which vary toward the end where the combustion line runs into the expansion line from the dilution of the last part of the charge by early produced neutral gases. Through excessive dilution of some part of the mixture in the cylinder, which it must be understood is probably not homogeneous, some of the gas may not burn and on succeeding strokes the diffusion may be more or less complete than before, allowing the incompleteness of the combustion to vary toward the end of the process. The actual mixture under combustion consists not merely of air and gas, but rather air, gas and burnt or neutral gases. Any variation of proportion of the quantity of air, gas or burnt gases to the whole that may occur will produce variations in combustion lines, but variations in combustion lines may just as well occur when the proportions of totals are constant, through lack of homogeneity of the mixture on successive strokes.

8 Excluding for the moment a consideration of neutral products the problem of securing a proper proportion of air to gas in the cylinder is one of orifice flow, and the failure to secure it may be analyzed on the basis of the laws covering orifice flow. In this connection it must be remembered that it is not volume proportions that are most important, but rather weight proportions, since it is a definite weight of air that is required to burn a definite weight of gas, although volume proportionality will follow if the pressure and temperature of both the air and the gas are constant and the same, which unfortunately is seldom true. The orifices through which the air and gas flow separately to form the mixture are of very peculiar forms, as a rule, and not the same either in size or form so that the laws of variation of proportion are reducible to the laws of variation in the weight of air per pound of gas flowing through separate orifices of different form and size at probably different temperatures and with different pressure drops or pressure heads.

9 It is well known that the coefficient of efflux for the flow of gases through orifices varies with the size of opening, shape of opening and velocity of flow or pressure head. Air enters the engine

cylinder under the influence of a pressure head represented by the cylinder vacuum. The gas, however, has a pressure higher than atmosphere if pressure gas and lower than atmosphere if suction producer gas, so that while the head causing the flow of air is the cylinder vacuum alone, the head causing the flow of gas when under pressures is the sum of the cylinder vacuum head and its own pressure head, and when under suction is the difference between the cylinder vacuum and the gas pipe vacuum. Gas pressures are, moreover, never constant in practice nor will any of the gas pressure regulators proposed and used make them constant nor reduce them uniformly to atmosphere because they always involve inertia effects of moving solid parts and of the gas itself.

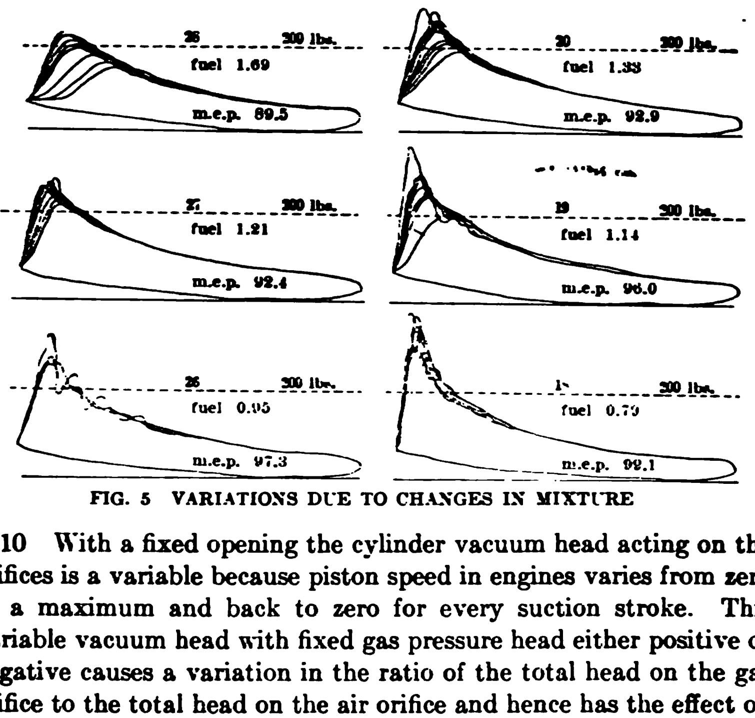

FIG. 5 VARIATIONS DUE TO CHANGES IN MIXTURE

10 With a fixed opening the cylinder vacuum head acting on the orifices is a variable because piston speed in engines varies from zero to a maximum and back to zero for every suction stroke. This variable vacuum head with fixed gas pressure head either positive or negative causes a variation in the ratio of the total head on the gas orifice to the total head on the air orifice and hence has the effect on varying proportions of air to gas throughout the stroke. In addition to this, whenever the gas is under pressure, and the opening fixed, the idle engine period, that is, the period of no suction, it allows time for the pressure gas to flow past the orifice and collect in the air chamber, or to collect and build up pressure at the orifice if it be of the closing kind, which would tend to make the mixture rich in gas at the beginning of the next stroke.

11 Intermittence of flow is another element which enters into the variation of proportion because it brings into play the inertia of the gas and the inertia of the air. A stream of air or gas cannot be started or stopped instantly, and as the masses to be moved are not the same the inertia will not be the same for the two, and one will tend thereby to lead in its flow over the other one, that which has the smaller mass leading. At the end of suction that which has the greater mass will continue its motion for the longer time.

12 It appears, therefore, to be an extremely difficult proposition, viewed entirely independent of the gas engine, to secure constant weight proportion between two gases flowing through two orifices into a partial vacuum through openings of different sizes and shape under heads compounded of the vacuum and the gas pressure with variable rates of flow, changes of barometer, gas pressure and the temperature of both gases and it is not surprising that variations

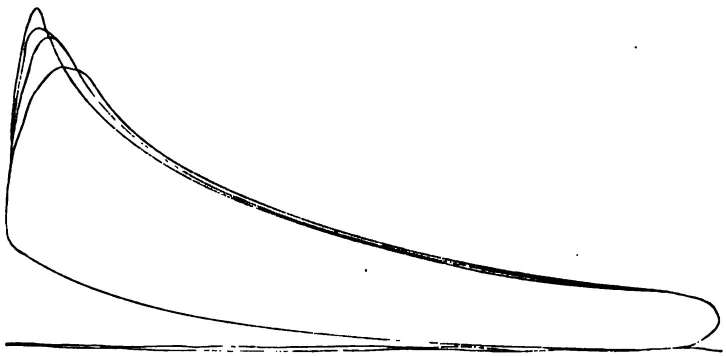

FIG. 6 VARIATIONS DUE TO CHANGES IN MIXTURE.

occur, but rather more surprising that the results are as uniform as they are. After having proportioned the air and the gas, the mechanism delivers it into a cylinder through a valve to an irregular head or clearance space where it mixes more or less uniformly with the neutral gases therein. These residual gases may have the same composition on successive strokes or may not, depending upon a variety of circumstances, some uncontrollable, such as diffusion, others under practical control, such as point of ignition and back pressure. A rather aggravated case of this mixture variation effect on various engine settings is given in Fig. 5, the fuel being gasolene and the engine a small one.

13 Another case not so aggravated, but much more common is shown in Fig. 6. This is from a medium size engine running on city gas. It is to be distinctly understood that the mixture variations

which occur in a hit-and-miss governed engine, before and after misses when the combustion chamber contains in the one case air after a miss and in another case burnt gases after an explosion, are excluded from this discussion and only the variations which occur in engines operating under steady and uniform conditions included.

EXPLOSIVE WAVES

14 The French scientist, Berthelot, gave the name "explosive wave" to a certain phenomenon observed in the combustion of explosive mixtures, which phenomenon was later more fully investigated by Mallard and Le Chatelier in "*Recherches Expérimentales et Théoriques sur la Combustion des Mélanges Gazeux Explosifs,*" and in recent years by Dixon and Bradshaw, Crussard and many others, which phenomenon may easily occur and does occur in gas engine cylinders. In some cases it is possible to define the conditions which will produce it and in other cases it is not. Examining the rate of propagation through a tube it is found that at times the propagation is uniform, at times mildly undulatory, indicated by waves of small amplitude, and at times violently undulatory, indicated by waves of great amplitude accompanied by shock and sound. This violently undulatory propagation has an extremely high rate and can be produced whenever there is a violent agitation of the mixture about to be ignited.

15 One sort of agitation producing this result and in use by early experimenters was a small stream of the mixture impinging into the main mass. An apparently different agitation though probably an identical one studied especially by later experimenters is a pressure wave or compression wave. It can be shown that if combustion be started in a tube, closed at one end, waves may be set up so violent as to cause extinction before the passage through the tube is completed. In this case the agitation is a result of a compression wave produced by the combustion itself. In engine cylinders this same sort of wave may exist. The motion of the piston itself during compression produces a compression wave which advances before it through the mixture and which probably reflects and superimposes or neutralizes, as accident may dictate, so that the entire mass is in a process of agitation during compression.

16 Inflammation started in such a mixture agitated either by streams of gas as the result of pockets in the combustion chamber or by compression waves, will sometimes be very violent, giving a true explosive wave, but may not exist at all. This seems to indicate

that the violent momentary pressures of the explosive wave crest result only when advancing waves superimpose one on another and synchronize with their reflections.

17 A simple experiment that can be performed by anyone will yield explosive waves of this sort on any gas engine if between the indicator and the engine cylinder there be connected a pocket with a small throat, which may be made of pipe fittings. An engine which

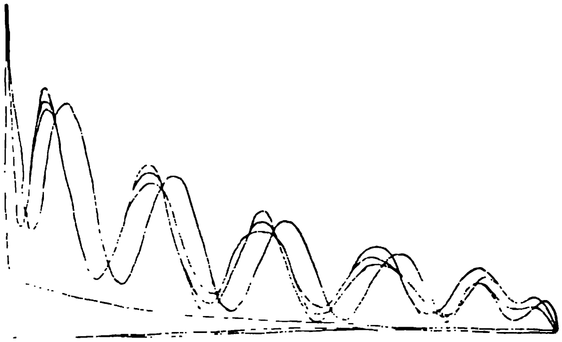

FIG. 7 CARD SHOWING EXPLOSIVE WAVE

gives a perfectly smooth combustion line without such a pocket will give with the pocket explosive waves even when the ignition is quite late. In nearly every engine these waves will be produced when the ignition takes place before dead center, that is, during the time when the mass is agitated by compression waves from the piston.

18 Fig. 7 shows an explosive wave from a kerosene engine having no hot bulb and a very good form of combustion chamber. Fig.

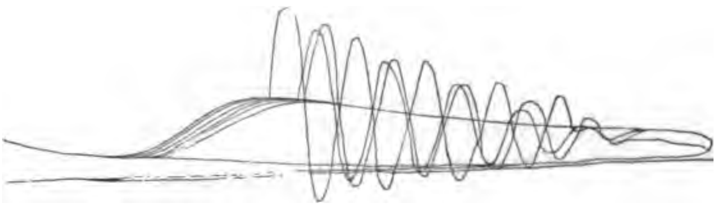

FIG. 8 CARD SHOWING EXPLOSIVE WAVE

8 shows for even very late ignition an extremely violent wave, so violent that it is shown for only part of the stroke, the pencil having jumped from the paper for the rest of the stroke. Fig. 9 shows a curious modification of this wave with a sort of harmonic at the crest. Fig. 10 is a record of a violent wave in a large oil engine of the hot bulb class, and Fig. 11 shows another less violent wave

taken from the same engine shortly after. These explosive waves are not to be confused with the occasional fluctuations of the indicator pencil due to the natural period of vibration of the piston and parallel motion of the indicator, although, according to my experience, the confusion is more likely to be the other way, the vibration of the indicator parts being more often the only explanation for the waves that are found. Furthermore it must be remembered that the true explosive wave will always be followed by the indicator inertia wave.

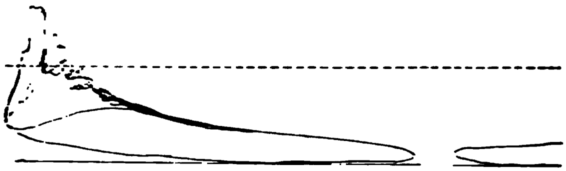

FIG. 9 CARD SHOWING EXPLOSIVE WAVE

19 It is interesting to compare these waves with the Mallard and Le Chatelier photographic records of some explosive waves of light. By passing a photographic plate across a tube in which the mixture is to be burned, the record will give an indication of the rate of propagation because one coördinate will represent time and the other will represent distance traveled by the flame. Fig. 12 and Fig. 13, reproduced from their report, show not only the primary uniform propagation

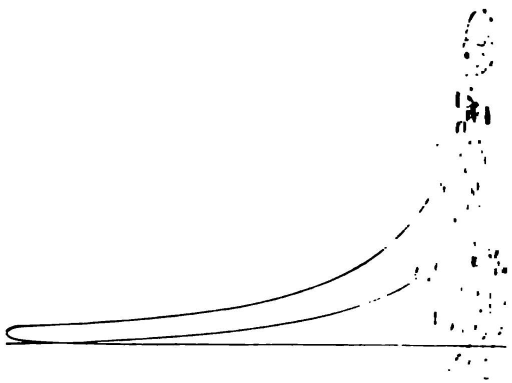

FIG. 10 LINES OF CARD INDICATING VIOLENT WAVE

indicated by the straight line, but also the violent explosive wave effects indicated by the wave of great amplitude, which ceases abruptly because it causes extinction. These waves are light waves and very similar indeed to the actual pressure waves recorded by our indicators. Occurring in engine cylinders they are elements not only of danger, but of interference with control and require attention for their elimination, but even in spite of great care often refuse to yield to any sort of treatment and persist in spite of the application of remedies.

PREIGNITION

20 Whenever on compression a mixture ignites itself much before dead center the phenomenon is called "preignition." Besides the many known easily avoidable causes, there are some that are difficult to understand. Any inward projecting part, such as a piece of asbestos gasket or rough edge of the casting, a bolt head, nut, piston compression plate, carbonized oil or possibly an ignitor, may get so overheated as to cause ignition. The compression causes a temperature increase, measured by the degree of the compression so that all parts of the gaseous mixture, except those directly in contact with walls, will suffer the same temperature rise, due to the compression.

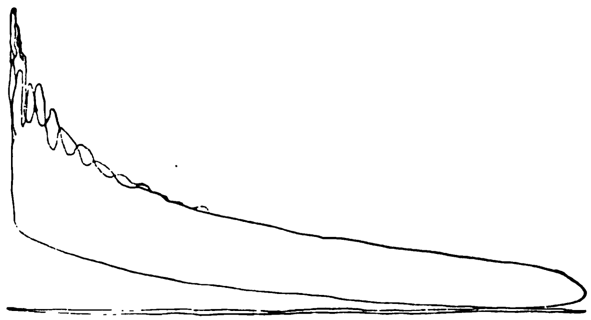

FIG. 11 FROM SAME ENGINE AS FIG. 10

If there is near any particle of mixture a source of heat other than the compression the temperature at that place will rise higher and may rise so much higher as to cause an ignition. It may be also that lack of homogeneity in the mixture will result in zones where the mixture has a lower temperature of ignition than at other places, for example, in places where lubricating oil is vaporizing or in the case of gasolene where the mixture is a little more rich in gasolene. This is another cause. In spite, however, of these and other traceable causes there seem to be still others, and these are mostly associated with the percentage of hydrogen in the gas.

21 At one time it was believed that the temperature of ignition of hydrogen was so low that the addition of hydrogen to a gas not previously containing it would lower the temperature of ignition of the mass, and designers, including the writer, went so far as to

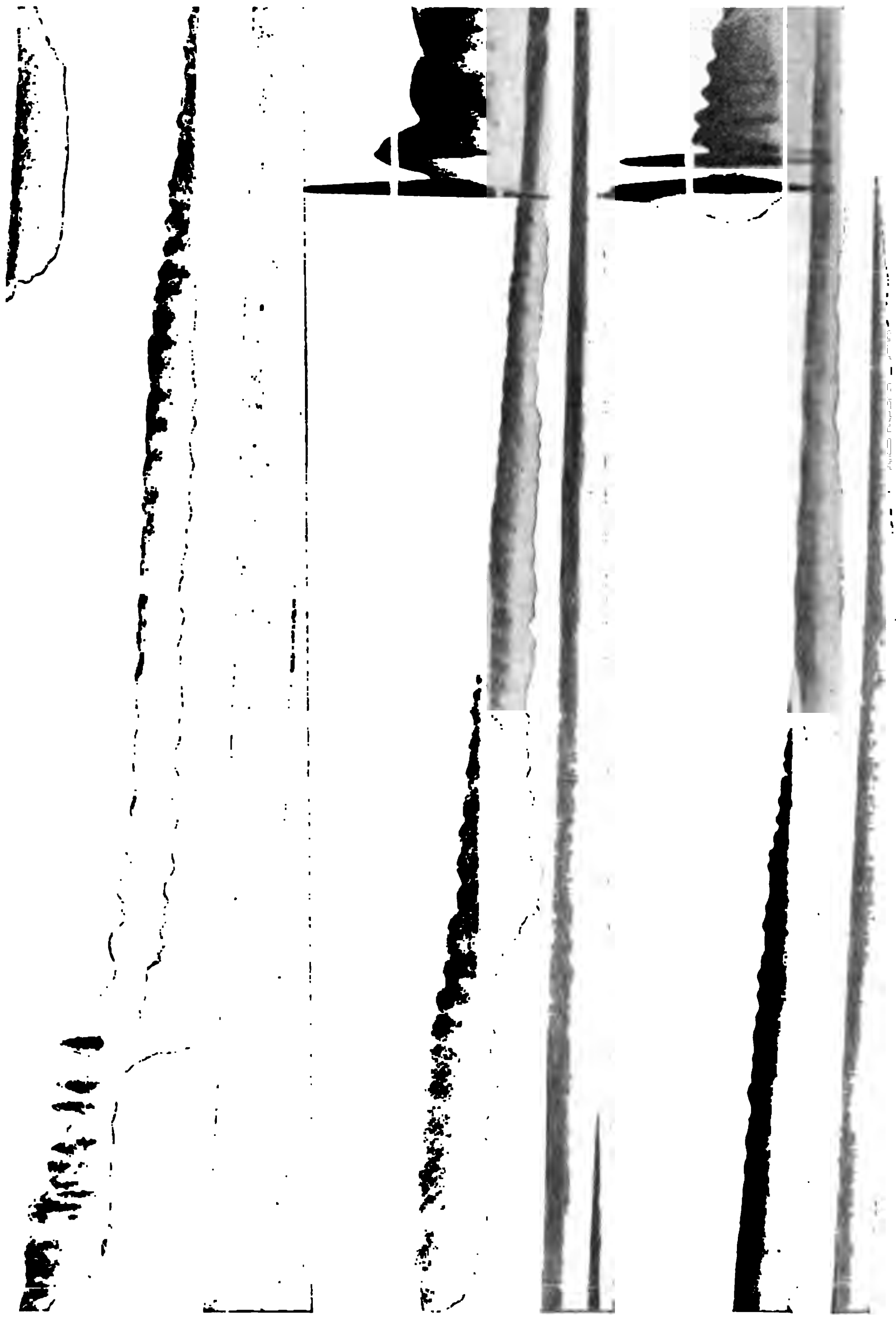

FIG. 12. PHOTOGRAPHIC REPRESENTATION OF EXPLOSIVE WAVES OF LIGHT.

FIG. 13 EXPLOSIVE WAVES OF LIGHT

announce figures for the reduction of compression for each per cent of hydrogen present that was necessary to prevent preignitions.

22 Repeated experiments by the different engine builders and by engineers not associated with the building of engines point conclusively to the fact that preignition may occur when the percentage of hydrogen is low and may not occur when it is high and again may occur when it is high and may not when it is low for a given engine running on a given compression, but there seems to be substantial agreement on the statement that if the hydrogen were absent there would be no preignition at this compression.

23 A considerably detailed investigation carried on partly in the laboratory at Columbia and partly in the field seemed to indicate that it was not the percentage of hydrogen in the gas that fixed the tendency to preignite, but rather some ratio of the hydrogen to the other elements present. The remedies applied commonly for preignition troubles are two-fold; first, a reduction in compression; second, an introduction of neutral elements, such as water to be vaporized into steam, steam itself or cooled and purified exhaust gases. This practice introduces greater variations in the mixtures than it is desirable to have, and is justified only in emergency, that the engine may continue to run.

24 An examination of the old values of the temperature of ignition for explosive mixtures throws no light whatever on the solution of this phenomenon, but some more recent determinations do. By dropping a weight on a plunger, closely fitting a cylinder containing a known gas mixture and measuring the plunger travel up to the point where it is stopped by the explosion the temperature of ignition may be calculated by the adiabatic law from the volume ratio in compression when the ignition takes place by the compression alone. This method of measurement was employed by Dr. K. G. Falk in the mechanical engineering laboratories of Columbia and gave for repeated trials of the same mixture at different times the results so consistently uniform that they seem to be very valuable. These were reported in the October meeting of the American Chemical Society and are here summarized.

HYDROGEN AND OXYGEN

Mixture by volumes	Atmospheres adiabatic compression	Ignition temperature corrected for moisture deg. cent.
$4H_2 + O_2$	47 maximum	878
$2H_2 + O_2$		813
$H_2 + O_2$	33 minimum	787
$H_2 + 2O_2$		803
$H_2 + 4O_2$		844

25 This indicates that the temperature of ignition of H and O varies with proportions and is lowest not for the mixture that burns to steam, but for equal parts so that H_2O_2 is the first product formed. The temperatures are those resulting from adiabatic compression to 33 atmospheres minimum and 47 atmospheres maximum, several times higher than ever attained in gas engines of the ordinary type.

CARBON MONOXID AND OXYGEN

Mixture by volume	Atmospheres adiabatic compression	Ignition temperature corrected for moisture deg. cent.
$6\,CO + O_2$	76 maximum	994
$4\,CO + O_2$		901
$2\,CO + O_2$	43 minimum	874
$CO + O_2$		904

26 The lowest temperature is obtained with the mixture $2\,CO + O_2$ with 43 atmospheric compressions which lies between the maximum and minimum for H and O, but the maximum value of 76 atmospheres for $6\,CO + O_2$ is much higher than the highest for H and O. It is interesting to note also that equal additions of CO or O act the same in raising the temperature of ignition.

27 The addition of neutral nitrogen to the H and O mixtures always raises the ignition temperature and the new temperature $T_{H,O,N,}$ for the mixture containing N may be written as a function of the old temperature $T_{H,O}$ as follows:

$$T_{H,O,N} = T_{H,O} + 30n$$

in which

$$n = \frac{\text{volume of inert gas}}{\text{volume of } H_2 \text{ or } O_2 \text{ (whichever is smaller)}}$$

Thus, the addition of $4\,N_2$ to the $H_2 + O_2$ mixture, which has the lowest temperature of ignition, raises the ignition temperature from 787 deg. cent. to 907 deg. cent., a value higher than for any of the H and O mixtures.

28 Similarly, for the CO and O mixtures an equation was found giving the temperatures resulting from additions of N, which is

$$T_{CO,\,O,N} = T_{CO,\,O} + 80\,m$$

$$\text{in which } m = \frac{\text{volume of inert gas}}{\text{volume of CO}}$$

29 Combinations of H, CO and O which approach the producer gases were found to have ignition temperatures which followed the

law of rise by addition of neutral. If the ignition temperature of the H and O part be calculated, considering the CO as inert and that for CO and O part calculated considering the H as inert then the lower value is found to agree with the observations by test. This indicates that the ignition temperature of complex mixtures is fixed by two of its components and their proportions to each other, all else acting to raise the temperature as inert or neutral gases.

30 Trials of alcohol gave a temperature of 973 deg. cent. at 62 atmospheres and fairly constant for over 100 per cent variation in quantity, while gasolene gave 902 deg. cent. with 47 atmospheres, constant for more than 300 per cent range in quantity.

31 These results explain the apparent inconsistency between percentage of hydrogen in the gas and the conditions of preignition. It appears from the figures given for the temperature of ignition that in a producer gas containing hydrogen and CO with various neutrals mixed with oxygen the temperature of ignition does not depend on either the hydrogen necessarily nor the CO necessarily in the mixture, but on the relation that one of these bears to the oxygen present and which one can be determined only by computing the temperatures of ignition for the value and taking that value which is lower. One very significant fact in addition to the above is brought out by these results, and that is that the ignition temperatures and compressions formed are all very much higher than those used in engines. No ordinary engine uses compressions anywhere near those determined for preignition.

32 It is evident, therefore, that as preignitions occur they are due not only to the compression, but also to other sources of heat. The interior parts must be hot enough in places to materially augment the temperatures produced by compression alone. As the final temperature, due to compression, bears a fixed relation to the initial temperature for any given compression that final temperature may be made higher not only by heat additions during the compression, but by a higher initial temperature. High temperature burnt gases retained in the cylinder are, therefore, detrimental and scavenging would be an assistance, but it is doubtful if initial temperatures are high enough in actual engines to account for the preignitions which occur, judged in the light of these ignition temperatures measured, and it is, therefore, extremely likely that all heat effects, not necessarily for the entire cylinder, but for some part, are the real causes and in addition the occasional presence of a certain sensitive proportion between oxygen and either CO or hydrogen.

33 The solution of the problem of controlling preignition resolves

itself into three parts; *a* Maintenance of proportion of the elements of the mixture to those having the higher temperature of ignition, provided this mixture will still contain enough oxygen to burn all the fuel present; *b* Care in securing as low an initial temperature of the mixture as possible by maintaining inlet passages cool and purging the cylinder as completely as possible of burnt gases. This also involves the maintenance of early ignition to reduce final release temperatures. *c* Care in designing the machine so that interior parts shall be as well cooled and as uniformly cooled as possible. A well cooled cylinder with one spot, such as a nut, poorly cooled may just as well be poorly cooled throughout.

34 The prevention of explosive waves entirely in engine cylinders seems to be impossible. They can be avoided to a large extent and practically eliminated by giving attention to the form of the combustion chamber and to the method of igniting so as to avoid the generation of successive waves that might superimpose, but precisely how this is to be done cannot be said at this time, and more research will be required before a solution is possible. It may appear in the light of complete information that no solution will ever be possible.

35 The maintenance of uniform cylinder mixtures involving, as it does, first, the correct and positive proportioning of air to gas, and later, the uniform mixing of this primary mixture with the burnt cylinder gases in always constant quantities, is a thing which is absolutely impossible with the present type of engine. Careful design can do much, but I feel it cannot overcome, so long as present types are adhered to, the numerous difficulties here presented.

36 These three phases of the general subject of our lack of control of internal combustion in exploding engines, namely, the maintenance of mixture proportions, the elimination of explosive waves and preignitions are all worthy of much study and are all difficult problems in themselves. It is hoped in this presentation of the conditions to be met that designers and builders of these engines, as well as the users, may be led to continue the investigations and to announce their results.

DISCUSSION

MR. LEWIS H. NASH In regard to the existence of explosive waves in the cylinder of a gas engine, I am inclined to doubt whether they exist at all, and, in order to make myself clear, I will refer to a little past history.

2 In the early days I was much troubled with explosive waves. These were of such violence as to break the indicator instantly. In order to try and avoid these high vibratory motions, we drilled small holes into the cylinder and attached the indicator through the usual thread and cock furnished with the instrument. Notwithstanding our use of very stiff springs, the vibrations were frequently strong enough to break the indicator mechanism. In order to overcome this, I made a little dash pot attachment for the indicator, in which oil was placed in a cylinder containing a piston loosely fitting in the same, and by means of this dash pot I reduced the amplitude of these vibrations until we no longer had any trouble from breaking instruments.

3 The card taken with violent explosive waves, so called, and one in which they did not appear, gave practically the same mean effective pressure. Therefore, the explosive waves did not seem to indicate any increase of power, but only the effect of an explosion.

4 One day we put the indicator close down in the head, drilled out a large hole in the cylinder and used an indicator without the dash pot. Greatly to our surprise there was no resulting disaster to the instrument. This led me to study the cause of the explosive wave action.

5 I believe, therefore, that the explosive wave action is simply a local phenomenon of the passage leading to the indicator, and that it has no existence in the body of the cylinder itself. I account for the action referred to in the following manner:

6 Suppose we have a small extended tube leading from the cylinder of an engine. This tube, after the first impulse, will contain a mixture of burnt gases. When the charge is compressed in the cylinder, a portion of this compressed explosive mixture is driven back into the tube. When the main charge is ignited the flame does not communicate itself instantly to this long, slender passage; therefore, the increased pressure in the cylinder serves to compress the gases in the tube to a pressure equal to that of the exploded charge in the main cylinder. In doing this, the small portion of unexploded mixture in this tube is ignited by compression, and in this manner every particle of mixture in this small tube explodes at once, the effect being like that produced by dynamite or other high explosive, only in a lesser degree. This secondary explosion in the connecting tube is the one of which the indicator takes note.

7 It will, therefore, be seen that these effects can be produced, either in a chamber connected by a small passage to the engine cylinder, or in a long pipe in which the time of transmission of the flame would be longer than the ignition due to compression.

8 The remedy for this is to drill the indicator hole of the full size of the tap drill directly into the cylinder, and to place the indicator as close to the cylinder chamber as is possible. Since we have done this, I have never seen a card showing the so-called "Explosive Waves" taken from our engines.

9 I offer this as an explanation, and wish to say in closing that while it may be possible that other pockets in a combustion chamber could cause explosive waves, I believe that they would be of small amplitude in the body of the combustion chamber itself, and that those that have been shown by the indicator have their origin in the connecting passage and are simply a local phenomenon.

PROF. W. H. KENERSON In my experience these same explosions occur under all sorts of conditions; under conditions where there is no possible preignition. Where kerosene is not used, these same explosions will occur, both with and without diaphragms.

MR. E. J. KUNZE In Professor Lucke's admirable paper he shows clearly that there are three disturbing influences ordinarily tending to act in such a manner as to cause variation in the combustion line and hence in the regulation of the gas engine, namely:

a Mixture variation,
b Explosive waves,
c Preignition.

Representing these by their initial letters, we may tabulate the points recorded in Professor Lucke's paper and check off these points as we find a possible solution of overcoming the difficulty involved.

M

a Pressure and temperature not constant,
b Suction of engine variable,
c Collection of charge in air chamber,
d Intermittence of flow,
e Vacuum effect,
f Proportion of air to gas,
g Dilution of charge by neutral gases.

E

a Method of ignition,
b Small impinging streams,
c Pockets in ducts and cylinder,
d Compression waves.

P

a Proper proportion of elements,
b Purging cylinder,
c Gas zones,
d Variation of mixture,
e Cooling inner cylinder wall,
f Cooling inlet passages,
g Inward projecting parts.

2 It would seem, from what has been said, that not only should the design of the gas engine receive more rational treatment and each part designed for the function which it is to exercise but also the gas generating apparatus should receive a like careful consideration.

3 Dr. Lucke's findings show that in a perfectly homogeneous gas it is possible to predict its ignition temperature if the proportions of H and O and CO and O are known; this leads us to the point that we may by properly proportioning the relations of H and O and CO and O, obtain a gas which shall have as high a degree of ignition as is expedient, and this would indicate that our method of gas manufacture for power purposes must be modified and the process made more uniform. We should therefore have the amount of water vapor which passes through the bed of fuel regulated according to the amount of gas produced. The draft should likewise be regulated; hence a two cycle engine with an exhauster for maintaining draft on the producer would seem the most rational unit. The fuel bed should be of uniform thickness, hence we should have an automatic feed to the producer; the fuel bed should be of uniform texture in order to prevent air shoots and channels especially around the outer edges, hence the fuel bed should be constantly stirred. For bituminous coal as fuel the hydro-carbon gases should be permanently fixed, hence the producer should be of the down draft variety. We would then have a constant proportion of the proper elements, P *a*.

4 If the gas is generated in a blast furnace, the gas ducts should be large and the gas enter the gas-holder in several directions. Propellers or other agitators should be used to keep the body of gas in the gas holder constantly in motion to prevent the localization of bodies of gas having various heat values.

5 If now a two cycle engine is used and the air and gas pumps which are required to compress the charge sufficiently to pass it into the cylinder are operated independently of the engine, we may have a *constant pressure of air and gas* M *a*, entirely independent of the *suction of the engine*, M *b*. This system can be very effectively adopted in multi-

unit plants by concentrating the pump work to serve the outlying engine cylinders, one air and one gas pump serving several engine cylinders.

6 There should be no *collection of charge*, M *c*, in the air chamber. Air alone should lie directly outside of the inlet valve, since any leakage of the valve may cause a back fire with disastrous effect. No charge should be made until it is passing into the cylinder; it should then be cut off by the action of the governor which should have as little mechanical work to do as possible. If the governor is of the inertia type, we are thus enabled to regulate the size of the charge at the latest point possible in a gas engine and here again we see an advantage of the two cycle over the four cycle in that the time between the cut off of the charge and explosion of the same may be reduced much more in the former than is possible in the latter.

7 If the ducts are so designed that the velocity of fluid is not changed quickly and the charge is admitted into the cylinder without serious checking, we should not be troubled by the inertia of the gas and air, and *intermittence of flow* M *d*, would be reduced to a minimum. Especially after leaving the mixing chamber should the charge be passed through as few turns as possible. Its course should be, to the greatest extent, unobstructed.

8 In the two cycle engine we are not troubled by the *effect of vacuum* M *e*, on the flow of the charge.

9 The gas having a constant heat value can then be thoroughly mixed with the *proper portion of air*, M *f*, before passing into the cylinder and this charge made to lie between two strata of air, one stratum lying at the piston head, the other at the cylinder head. As the load decreases the charge of combustible mixture may be decreased proportionately and the charges of air proportionately increased so that for varying loads we would have constant compression and at least for the most of the combustible charge, constant mixture, only the outer portion being materially mingled with the air strata.

10 Ignition, E *a*, should be done from several points in order to insure certainty of ignition and hasten the flame proportion. It is well to place the igniters at different distances from the end of the cylinder so that the charge may ignite under its most favorable condition.

11 The most logical method of charge admission is at the end of the cylinder in line with the axis, but ordinarily such admission would puncture the core, *i.e.*, the incoming charge would follow the line of least resistance, which is the center, and the tendency would be to cause an annular body of exhaust gases to lie along the cylinder walls.

12 If we consider the plane of the orifice to be made up of a number of annular rings and assume the center core to have a given velocity, then the velocity of the points in the annular rings will be reduced as the area increases. We thus find points on our curve.

13 With a wave front as shown in Fig. 2 much of the comb mixture would be discharged through the exhaust ports before the cylinder had been thoroughly *purged of its exhaust* gases. The effect would be not only to displace some of the incoming charge and by the addition

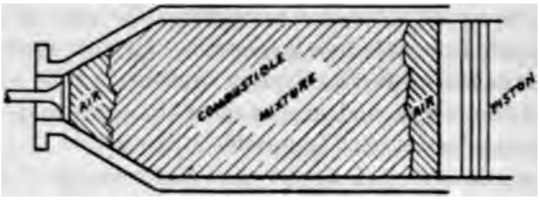

FIG 1

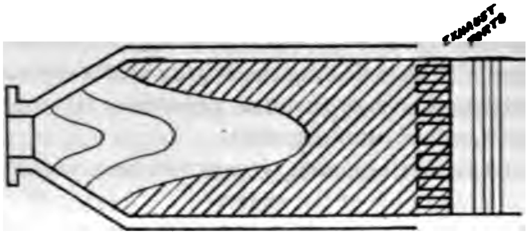

FIG 2.

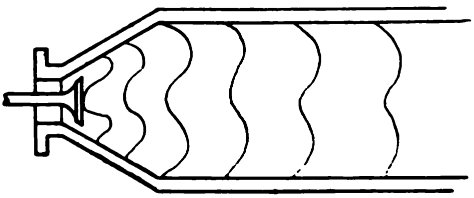

FIG. 3.

DIAGRAMS ILLUSTRATING MIXTURE IN TWO-CYCLE ENGINE

to the same of the heat of these gases and that of the cylinder wall which had not been properly cooled, to expand this incoming charge, but also to increase the initial temperature and hence reduce the amount of compression pressure which would otherwise be permitted.

14 If we more nearly flatten the wave front by using the inlet valve as a baffle plate, all these objections will be overcome; the peak of the wave is eliminated, P *b*.

15 The shape of the modified wave shown can be verified by constructing a model of strips of wood about one-eighth inch high and of the shape of the contour of the cylinder, as shown with the inlet valve in opened position, placing these wood strips between glass or other transparent material and blowing smoke through the orifice. Successive puffing will show that the several bodies of smoke do not whirl around but fill the area completely and pass through the cyl nder without intermingling; another feature which goes to support the stratification theory.

16 By this means the cool scavenger air first admitted cools the inner surface of the cylinder wall most effectively and evenly and this directly before the charge enters the cylinder. Thus in this case the heat stored up in the cylinder walls during the expansion of gases tends to keep the walls hot during the next expansion of charge, but the cooling of the inner portion of the walls permitted the admission of a maximum volume of charge and compressing same to a maximum degree of compression pressure before the heat in the walls had time to effect the charge.

17 If the charges are thus smoothly admitted into the cylinder, we will not be troubled with *impinging streams*, E *b*, *pockets*, E *c*, and *gas zones*, P *c*.

18 The evil effect of the *compression wave*, E *d*, will at least be reduced to a minimum if the mixture is uniform and the streaming of various bodies of gas having different heat values into one another, mixing as they do with difficulty, is avoided.

19 This phenomenon of failing to unite readily into a homogeneous mass, at least, partially supports the stratification theory when the latter is properly followed.

20 *Variation of mixture*, P *d*, due to admission of exhaust gases, will not trouble us because we will have no exhaust gases left in the cylinder and we will have no need to *dilute*, M *g*, our well proportioned homogeneous gas mixture with cooled exhaust gases.

21 Our cylinder wall will certainly be well cooled, P *e*, and as our cylinder head may be of the most simple type (the frustum of a cone), it can be easily and uniformly cooled and the inlet passages may therefore be well cooled, P *f*.

22 All *projecting pieces*, P *g*, with the exception of the igniters, may be avoided and even these may be at least partially water cooled.

MR. E. RATHBUN[1] As an explanation of the phenomena relating to explosion waves, so called, I suggest an auxiliary explosion in the

[1]With George J. Rathbun, Toledo, Ohio.

indicator piping, after the combustion in the engine cylinder. This is due to a combustible mixture remaining there and becoming ignited at a very high temperature and compression. Such an explosion would be in the nature of a blow upon the indicator spring.

2 On the card Fig. 1 there is absolutely no indication of wave effect or excessive pressure in the indicator until after the expansion stroke has begun. The stroke has progressed 20, possibly 30 degrees, before any effect is obtained, then a sudden impulse strikes the indicator. I find that these waves indicate vibration in equal times. This would seem to show that the effect is due to vibration of the indicator spring and connecting parts.

3 There may also be such a condition as vibration of the working fluid itself, but up to the present time I have seen no indication of it

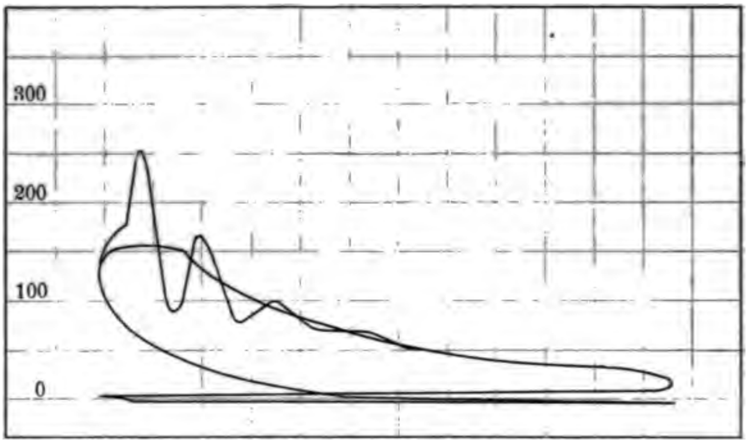

FIG. 1 DIAGRAM SHOWING LATENESS OF WAVES

in the discussion; that is, all the indicators have been attached at some distance from the cylinder, and Professor Lucke showed also that in tests which did not show waves, the addition of a chamber to the rig itself would produce that effect. We have also in regular practice been able to regulate these effects; that is, obtain a wave card by the regulation of a globe valve in the indicator pipe. If we take an indicator card with this valve wide open, we get wave effects, but as the valve is closed the wave will gradually disappear until there will be no such indication. It would appear that the scavenging was insufficient to produce that effect.

Dr. S. A. Moss Why does Professor Lucke conclude that the waves shown in Fig. 7 to 11 inclusive, are not the indicator vibrations alluded to? I have seen many such waves on indicator cards and have always been inclined to assign them to indicator vibrations, since I know of no positive evidence that they truly represent variations of pressure in the cylinder. I call particular attention to the fact that the waves in Fig. 7 have greatest length near the center and least length near the ends of the stroke, indicating that they probably have the same time period. This seems to me to give a strong presumption that they are indicator vibrations only.

MR. R. E. MATHOT Without wishing to detract from the very valuable report presented by Professor Lucke, I would like to discuss some phenomena shown by the indicator diagrams reproduced in his paper. Unless a special study of such cards is made, it is difficult to determine whether the irregularities in diagrams are due to special phenomena occurring in the gas engine cylinder, or are simply the result of faulty operation of the indicator itself.

2 For instance, in Fig. 4, I do not agree with Professor Lucke's statements regarding the curves in the upper expansion lines. These undulations are not due to waves in the burning mixture, but are caused by the inertia of the indicator piston and usually appear when the indicator spring is too heavy for the running speed.

3 Fig. 11 shows a different form of wave in the beginning of the expansion curve, such as is generally obtained when preignition or very sharp and severe explosions take place, either in the cylinder or in the indicator. In the latter case, a common phenomenon, very rapid vibration is communicated to the tracer, and to the moving lever of the indicator.

4 When a powerful explosion takes place, as the result of the combined effect of preignition and too rich mixture, the top of the initial pressure line, instead of being smooth, is really a dotted line, showing that the tracer was vibrating on the paper.

5 In order to determine and locate such troubles, I use a special attachment, consisting of a short tube fitted in the indicator cylinder, immediately under the piston. This tube prevents the piston from moving in the lower part of the cylinder, and as a consequence the tracer will only record the upper part of the diagram, thus showing the top of the explosion line and the beginning of the expansion line. The stroke of the moving parts of the indicator being reduced to a minimum, they will no longer be subjected to inertia, and cards like Fig. 4 and 17 will show regular lines without waves, evidently proving that this wave phenomenon has taken place, not in the engine, but in the indicator itself.

6 Let us now consider Fig. 7 and 8, showing from eight to ten undulations while expansion takes place; that is, during one-half revolution of the engine at a minimum speed of say 200 r.p.m. If the undulations really represent wave effects, the indicator should give true and accurate records, even when used on an engine running at 2 by 8 (or 10) by 200 = 3200 to 4000 r.p.m. while it is well known by experienced testers that, no matter what indicator makers may claim, no instrument of standard construction will give reliable information on gas engines turning higher than 450 to 500 r.p.m.

7 With reference to faulty indications given by this apparatus, I might also mention the apparent "scavenging" shown by an exhaust line traced under the atmospheric line, when a weak spring or a stop of the piston of the indicator is used to record the backpressure and the vacuum.

8 From the examination of these so-called "vacuum cards" many makers claim that their engines are "scavenging," while the diagram shows merely an inertia effect of the moving parts of the indicator that have caused the exhaust line to show a vacuum.

9 In fact, in the study of about 500 tests, made since 1900 on all sorts of engines, I have perhaps found 20 or 25 cases where scavenging really occurred in the engine's cylinder.

10 Experience has shown how to determine the right spring to use with a good indicator for recording both true vacuum and back-pressure. This spring should have about a 25 lb. scale, just strong enough to overcome the inertia of the moving parts, and light enough to record distinctly both vacuum and back-pressure, as compared with the atmospheric line.

11 I do not wish, however, to deny the existence of explosive waves of the nature of those mentioned and demonstrated by Professor Lucke's experiments. I would add, that physical properties such as lack of homogeneity in the mixtures, may generate explosive waves, or more accurately, waves in the explosions. These factors are of a mechanical nature such as vibrations in the walls of the combustion chamber and in the flat bottom of the piston when sharp and sudden explosions take place. The waves are usually generated from very rich mixtures, which have a tendency to preignite or to fire early, as for instance, when the piston is at dead center and almost momentarily at rest. If these metal vibrations happen to synchronize with those propagated in the fluid, waves result that may be detected in the diagram.

12 I wish Professor Lucke would continue his interesting experiments on larger engines, since they would surely result in a contribution to the subject.

The Author From the discussions that have been presented regarding some of the indicator card waves it is evident that I have not made myself clear in the body of the paper on the differences between explosive waves and indicator inertia waves. The explosive wave, as is indicated by its other name of "detonating wave," is generally a manifestation of violent momentarily localized pressure which would start oscillations of the indicator mechanism. These indicator oscillations are easily distinguishable by their periods and damping characteristics and the fact that they are present in most of the cards I have presented does not prove the contention of some of the gentlemen who have spoken on the subject that the explosive wave is absent. It rather proves that the explosive wave was of a detonating sort, which may or may not have persisted as long as the indicator wave. It must be borne in mind that there is ample evidence to prove that the indicator wave would not be present with a properly selected spring unless the detonating or explosive wave had first appeared. It is extremely likely that the gas wave does not persist as long as the indicator wave, and this fact is probably the reason for many misinterpretations.

[redacted]

No. 1168

THE EVOLUTION OF THE INTERNAL COMBUSTION ENGINE

The Problem of the Internal Combustion Engine Stated in the Light of Past Experience

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Member of the Society

Regulation and Reliability Versus Efficiency

GENERAL CONSIDERATIONS

The question of the current or future development of the internal combustion engine does not turn centrally upon how to improve its fuel efficiency. It turns, instead, upon the problem of its proper regulation. Since both of these statements may seem surprising to many readers, it is necessary to give them some support from the past history of the art.

2 The general history of the heat-engine has not been guided, to any perceptible degree, by considerations of thermodynamic efficiency but by those of commercial efficiency; and the gas-engine, although supreme in thermodynamic efficiency, has been quite secondary in its commercial efficiency, as measured by the cost of fuel per horse power hour. Viewing all types of prime mover broadly, it has never been the most efficient one which has obtained paramount favor in the past. Indeed, it has usually been almost the opposite. The hot air engine, for instance, a type always fascinating to inventors because of its thermodynamic refinements, has never succeeded on the market, in spite of its superior fuel records. The history of the regenerator, viewing the engines which make use of it as a distinct type of prime mover, reveals the same thing. It is the steam engine, on the other hand, whose prime characteristics are mediocre efficiency and ability to pull hard whenever requested, which has always been

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far the most popular source of power. It may not save coal, but it saves everything else.

3 Yet even among the several types of steam engine it has never been the most efficient design which has succeeded most markedly. The winning considerations, in the steam engine field, are those of capacity for power in terms of space or weight, reliability and controllability or adaptability, coupled with reasonable efficiency. Of course, other things being the same, a more efficient has always been preferred to a less efficient engine; but greater efficiency has nearly always been accompanied by a difference in those other things; reliability and adaptability have not been so great; and the competition has always been reduced, in the long run, to those other considerations.

4 The history of the gas engine fairly bristles with this same fact. It is to be remembered that it is only in the more recent portion of this history that we may couple with the gas engine the idea of a power gas producer or a supply of natural or blast furnace gas. The gas engine's spurs were won long before any of these later aids appeared appreciably upon the field. During all of that preliminary period *the fuel cost per horse power from a gas engine or oil engine was higher than from any other prime mover known in the arts!*

5 A still more important fact in the history of the gas engine than the inefficacy of thermodynamic refinements is its opposite, namely, that the situations which best reveal the limitations of the gas engine are not those demanding a higher thermodynamic efficiency than it can give. Neither are they the demands for a cheaper grade of fuel than it may consume. There is no evidence anywhere that cheap power is what is wanted, any more than there is that cheap men are what is wanted. Instead, it is those situations which demand either better reliability or better controllability than the gas engine has to offer, which shut it out from consideration in competition with the steam engine. Of the hundreds of gas works existing in the United States, for instance, all of them using power and all of them able to make additional illuminating gas, or to divert "blue gas" as rich as blast furnace gas, for a gas engine drive without appreciable cost, *not a half dozen use gas engines.* They will not tolerate them on the premises. At Hundred, W. Va., is a pumping station for natural gas which daily handles millions of cubic feet of gas which is worth almost nothing, at that locality, to its owners, who also own the pumping station. Yet all the power used in the station is developed from steam boilers and Corliss engines. Ask the reason why, and "Unreliability of gas-engines" is the answer.

6 For all of these reasons it must be accepted in the premises that future progress of the gas engine which most of us believe to be both possible and inevitable, must advance along lines leading to a greater degree of reliability, controllability and adaptability, into a better parallel with the solid preëminence of the steam engine in these features, and not necessarily or primarily along lines aimed at a greater thermodynamic or pecuniary fuel efficiency. Indeed, it seems to be already true to-day that almost any degree of efficiency is open to the designer or purchaser of a gas engine who is willing to accept its cost in other considerations; just as almost any speed of railroad or transatlantic travel is possible, in an engineering sense, if its cost be accepted.

7 But a choice in degree of reliability is not thus open as is choice in efficiency. If reliability be desired, the gas engine, as things stand now, must be abandoned for the steam engine. For these reasons it is the aim of this paper to state some considerations which affect the problem of gas engine *regulation*, *reliability* and *flexibility*, with a view to guiding the imagination along those grooves which it is felt must demark and limit the direction of future progress. For this purpose fundamental considerations are sufficient.

THE HIT OR MISS PLAN

8 In order to state the problem clearly it is necessary to refer first to that method of regulation which has now come to have an interest merely historic, although it is still applied frequently to small engines. This method is the one commonly known as the hit or miss plan, wherein the governor may choose only between admitting gas fully to the cylinder, for a given cycle, and shutting it off entirely.

9 Viewed from the standpoint of modern steam engine regulation, this method is unspeakably bad. Its common title "hit or miss," while based originally upon its mechanical method of action, applies equally well to the result attained. The regulation accomplished is distinctly "hit or miss" in quality. Chronographic measurements of the speed of good engines of this type show variations within each cycle as great as six per cent *under constant load.* Yet the average speed per minute varies often only two or three per cent between full and light load.

10 The poor result of this plan is due to four distinct factors, all but one of them lying outside of the question of governor design.

11 Of these the first in importance is the fact that for any given

cycle the governor is given no chance to *grade* the power. It may choose only between turning on maximum power and zero power.

12 Secondly, the poor regulation is due to the fact that in each cycle the power needed for compressing the next charge is drawn from the fly wheel just at the end of the idle period of the cycle, when the external load, already maintained for three-quarters of a cycle without impulse from the piston, has forced the speed to drop below normal.

13 Thirdly, the poor regulation is due to the fact that the time at which the governor must declare to the gas admission valve whether the next cycle is to contain an explosion or not, *is previous to the time of development of that explosion by more than an entire revolution* of the fly-wheel.

14 It is merely as an aggravation of these three fundamental faults that the fourth enters. The small governors usually supplied with these "hit or miss" engines contain a vital defect in that, while the valve-gear permits no gradation of power, the governor insists upon grading its own action. That is to say, the ordinary non-synchronous fly-ball or pendulum governor assumes a different position for each speed of engine between a lower limit, for maximum power and minimum speed, and a higher one for zero power and maximum speed. But in the "hit or miss" type of gas engine violent fluctuation of power, from one extreme to the other, is the only thing possible. The best will be gotten out of a bad situation when the leap from one extreme to the other, from an explosion to a miss, is taken with as great decision as possible.

15 But this the ordinary gas engine governor quite fails to do. In its carefully graded action there is only one point, that where one knife edge is about to ride or miss the other, where it can accomplish any governing. But at this point it never acts with decision. It vacillates, and often is entrapped, by the arrival of the decisive instant just as it swings a little to one side, into doing what the next instant reveals to have been the wrong thing. Explosions and misses are not alternated in regularity, but are unnaturally bunched.

16 Such action would be entirely corrected by the use of a synchronous governor in place of the non-synchronous one. The former is useless for steam engine work, where gradation of power is the one thing desired. But for gas engine work, where gradation of power is the one thing impossible, it is ideal. It would throw the gas admission cam into and out of gear with decision, which is all that can be done.

MODERN PLANS OF GOVERNING

17 The next step forward in methods of governing gas engines may be passed over briefly. It consisted in allowing an impulse to be developed at each cycle, but set the governor to grading the amount of gas admitted with each charge. This plan was better than the "hit or miss," in its regulation, but gave very weak mixtures under all loads appreciably below the maximum; and as a weak mixture delays the period of inflammation the heat was apt to be developed, under lighter loads, too late in the stroke to permit the work being gotten out of it. The plan has now virtually been discarded.

18 To-day the governing of the majority of larger engines is performed in one of two ways. Either the charge is throttled during its entrance to the cylinder, the proportion of gas to air remaining normal, or else the suction valve closes at a point in the suction stroke determined by the governor, whereupon the charge must expand below atmospheric pressure as the suction stroke is completed. In either case the result is much the same. The modification of the impulse depends upon the existence within the cylinder, at the beginning of the compression stroke, of a charge of normal mixture of gas and air at a pressure more or less below atmospheric pressure.

19 This initial pressure before compression, of course, varies with the load, from atmospheric or near there at maximum load down to a fair degree of vacuum at light loads. It accomplishes an excellent gradation of the energy of each impulse to suit the load. The standard form of indicator-card which it produces is shown in Fig. 1, wherein *AA* is the normal or average load card, *BB* the maximum-load card and *CC* the card of some fractional load.

20 The objections to this plan, however, are twofold. In the first place, it still imposes upon the governing mechanism a delay of a complete revolution between the time when the governor may last decide what is to be the energy of the next impulse and the actual development of that impulse. This is far better than in the "hit or miss" system, but it is still far behind steam engine practice, to which, as a standard, gas engine practice will always find itself compared until it excels it. For in steam engines the working stroke is already under way when the governor finally decides what is to be the vigor of that stroke.

21 It is also to be noted that the multiplication of cylinders is no remedy for this defect. Each impulse is still apportioned by a governor action which took place one revolution previously.

22 Secondly, any variation of the load from the maximum

inevitably drops the degree of compression from the maximum. Now the efficiency of the cycle is directly associated with the degree of compression. In the pure Otto cycle, unmodified by throttling or cut-off during suction or by any provision for the expansion of the gases beyond their original volume at suction, the theoretic efficiency F varies with the compression-ratio R according to the formula

$$F = 1 - R^{-0.287}$$

Fig. 2 shows this relationship graphically. It is based upon an atmospheric pressure of 14.5 pounds. as are all other diagrams in this

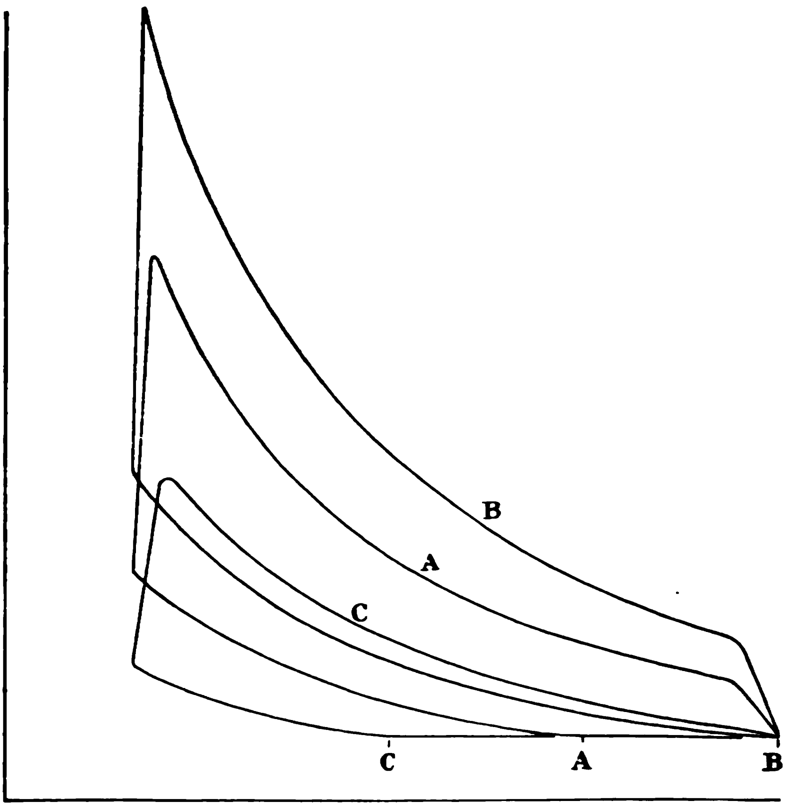

FIG. 1 GOVERNING BY VARIABLE CUT-OFF OF SUCTION

article. If it be remembered that the cost of the engine is roughly proportional to the maximum pressure in the cylinder, and this again the degree of compression, it is plain from Fig. 2 with what steadily increasing cost is obtained each decreasing increment of efficiency, which may be sought in the standard Otto cycle by increasing the average or normal compression.

23 On the other hand, Fig. 2 also shows how the decrease in compression due to governing by the method shown in Fig. 1 may be only moderately detrimental to the efficiency, provided the lowest degree of compression amounts to some 60 pounds gage pressure. In the blast furnace gas engines this requirement may be met; but with other and more inflammable fuels the maximum degree of compression must be kept so low, in order to avoid pre-ignition, that only a moderate degree of governing reduces it below the permissible figure.

24 This second objection, however, is partially balanced by a minor gain incidental to the lighter loads, namely, the increasing degree to which the expansion of the hot gases beyond their original atmospheric volume becomes possible as the load falls off. That is

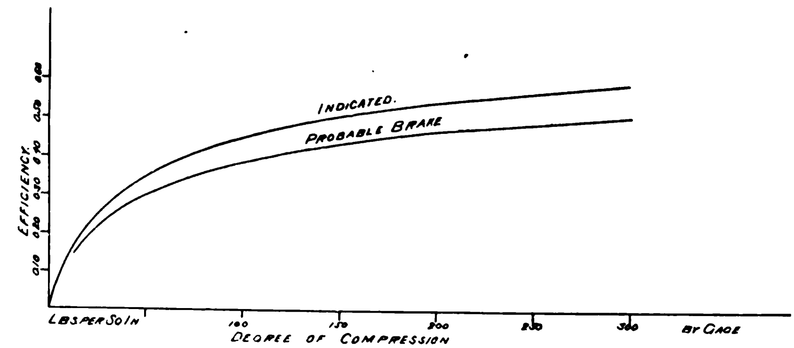

FIG. 2 RELATION OF EFFICIENCY TO COMPRESSION, NEGLECTING OVER-EXPANSION

to say, all work areas to the right of points A or C, in Fig. 1, represent the incidental gain, at shortened cut off, of work which is quite extra to the normal or pure Otto cycle to which Fig. 2 applies. This extra work from completed expansion becomes greater in proportion as the cut off becomes shorter, until the point is reached where the expansion line drops below atmospheric at the end of the stroke, after which it begins to decrease.

25 Fig. 3 shows the degree to which this fact is effective in keeping up the efficiency at fractional loads, in spite of the decreased compression due to the cut off on the suction stroke. In Curve T, Fig. 3, the maximum compression pressure is assumed to be 100 pounds by gage, and the explosion pressures are assumed to be three times the compression pressures. The exponent of compression and that of expansion down to the original volume is taken as 1.3; beyond that

point in the expansion it is taken as 1.1. It is further assumed that there is no scavenging and no delay in combustion. The mechanical friction is taken at 13 per cent at full load.

26 While these assumptions are too dogmatic to apply accurately to actual practice, yet they are the only ones practicable and they serve well enough to illustrate the point in mind. The result is seen to be a curve which holds up its efficiency quite well as cut offs shorten from full stroke to half stroke. Below that the efficiency drops off more rapidly.

27 Curve *A* gives a sample of actual modern engine practice of an excellent quality. On the shorter cut offs it shows the value of the delayed combustion which always accompanies short cut offs, from the greater proportion of burnt gases to fresh charge. This delayed

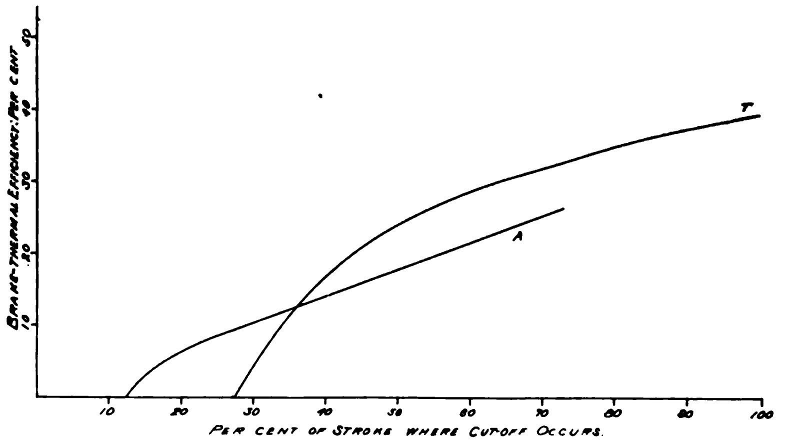

FIG. 3 RELATION OF EFFICIENCY TO CUT-OFF, INCLUDING OVER-EXPANSION AND RATE OF COMBUSTION

combustion, which is an unquestioned source of loss at full loads, thus plays a beneficial part at the shorter cut offs which constitutes an interesting parallel with the effect of wire drawing upon steam engine efficiencies; for the wire drawing of steam, which is unquestionably harmful at the longer cut offs, becomes positively beneficial at cut offs shorter than about one-eighth stroke.

28 If the engine of curve *A* had the best general efficiency which has been reported, instead of being only a good average the upper portion of curve *A* would have coincided closely with curve *T*.

29 But the chief lesson to be drawn from Fig. 3 yet remains to be stated. It is that the best practice yet attained with the modern gas engine leaves its efficiency curve still in a form sloping from a *maximum efficiency at maximum loads* to a lesser efficiency at all

lighter loads. In this peculiar, though fundamental, characteristic the gas engine stands alone, the writer believes, amidst the entire array of devices utilized by the power engineer. Steam engines, boilers, dynamos, gas producers, pumps, and even men, all have their point of maximum efficiency at a load considerably below their maximum possible out put. This point of maximum efficiency, or slightly above it, is understood to be the capacity at which they should be rated. Above that rating they will carry an overload ranging from 25 to 75 per cent in engines, from 20 to 200 per cent in boilers and from 50 to 100 per cent in dynamos. When subjected to this overload they are not expected to hold up the best of efficiency; but they are expected to sustain the work with operative satisfaction. At capacities below the rated load the efficiency is supposed to remain constant down to, say one-half or two-thirds of the rated capacity, below which point it may fall off rapidly without exciting censure.

30 But in the gas engine all is quite different; and this difference has had more to do with its history than has any other of its features, after the primal one of the nature of its fuel. During the greater part of that history, gas engines have been habitually rated right up to their maximum capacity. Yet every engine buyer knows that his engine's load will be at its maximum for only a small fraction of the time of operation. During the bulk of the engine's activity it must handle resistances amounting to some appreciable, although varying, fraction of the maximum.

31 This must lead to two things. In the first place, the average efficiency of the engine when engaged in actual work will be far below that shown on the maker's test plate, where the engine is carefully tested at its maximum, or rated, power. Secondly, the buyer, after having met with a sufficient number of disasters to teach him, learns to discount the maker's rating in a way which he never needs to do with other apparatus.

32 The first of these objections can be eliminated by mere honesty on the part of the maker; but the process has been a very slow one. The second objection cannot be so easily overcome. A man may build a gas engine capable of 125 horse power and be honest enough to sell it as a 100 horse power engine, which it really is. But he cannot affect the fact that the user must run his engine, under its usual load of from 80 to 100 horse power, at an efficiency far below what is actually obtainable under more favorable, but yet actual, conditions, namely, maximum load. This is the Gordian knot of gas engine regulation which no one has yet had the skill to untie, and which

the buyer usually cuts by "cutting" the gas engine and buying a steam engine.

CONCLUSIONS TO BE DRAWN AS TO THE TRUE OUTLINE OF THE PROBLEM

33 To summarize this résumé of the history of the gas engine then, the following appear to be the salient features of the premises from which its future progress must be predicted.

34 The advantages which have hitherto been cogent in its favor and the extension of which are therefore to be sought, are:

a *Not* solely in increased fuel efficiency—for with all fuels except blast furnace and producer gas, a gas engine costs more for fuel than does steam, and with either blast-furnace or producer gas its fuel is so cheap that no ordinary variation in its efficiency will appreciably affect its use;

b But chiefly in the nature of its fuel—because of the transportability, cleanliness, safety and low incidental labor-cost of gaseous or liquid fuel rather than the cheapness of the fuel itself. And of these the chief is its transportability, eliminating the need for a boiler plant. Every gas or oil engine not coupled directly to its own producer is an example of power transmission upon the most efficient plan known to man.

c Quickness of getting into action.

35 The *disadvantages* which must be eliminated are:

a *Unreliability*,—for a gas engine may, and commonly does, "lie down on its job" at any moment.

b *Lack of margin of power*,—for, when overloaded, instead of pulling slowly and inefficiently but more and more insistently, as the steam engine does, it "lies down" again.

c *Wrong characteristic*,—its average efficiency under medium load is far below its maximum efficiency.

d *Poor regulation*,—the governor's action determining any given impulse must always antedate the exertion of that impulse by one revolution of the fly-wheel.

e *Irreversibility*. Although several forms of reversing gas engines have appeared upon the market from time to time, the consensus of opinion is that the accomplishment is an unnatural one for the explosive cycle and that it has cost more, in complexity of mechanism and uncertainty of action, than it was worth.

36 It is because these features stand out boldly from the history of the gas engine, and have done so for years, that the writer has held to the following platform as defining the field of the future development of the world's heat engines, viz:

a Reliance upon liquid and gaseous fuels, rather than upon the direct use of solid fuel will steadily and rapidly increase.

b Questions of thermodynamic efficiency will hold a quite secondary place. Progress in efficiency will be made, but it will be incidental to, rather than commanding and guiding, the progress made in other lines.

c Questions of mechanical and commercial efficiency will be uppermost, and will be most active along the following lines:

1 *Reliability;*

2 *Wide margin of power over the most efficient capacity;*

3 *Regulation of each working impulse by a governor action occurring during the performance of that impulse;*

4 Reversibility;

5 General flexibility for the development, transmission and subdivision of power, at variable speeds and for divers purposes.

37 In all the above directions the steam engine sets, by example, a standard which, while plainly not perfection, is yet far ahead of existing gas engine practice. Its value has been proved by generations of experience. The gas engine of the future will not be exactly like the steam engine of today, but it will be more like that machine than it is like the gas engine of today.

THE SOLUTION OF THE PROBLEM

Modification of the Simple Otto Type Engine

THE VARIATION OF THE CLEARANCE-SPACE

38 In the above list of desiderata, item 2, if not the one of the most pressing importance, seems to be attainable with the least modification of the existing engine and its cycle. Let us imagine an engine in which the governing is done by cut off on the suction stroke, and in which the clearance space is variable in proportion with the volume of atmospheric charge taken in. The results to be expected from such an engine are shown by the indicator cards of Fig. 4 and the characteristic efficiency curves of Fig. 5. In Fig. 4 the normal

load card and its corresponding clearance space are shown by the full lines, marked *N*. The overload or maximum card and its clearance are shown by the broken and dotted lines, marked *O*. The half load card and clearance are shown by the broken lines, marked *H*.

¶ 39 In Fig. 5 the curve A_C shows the brake-efficiency of an existing engine of the better class. It is the same curve as A of Fig 3, but laid off to a new horizontal scale, viz: in terms of cut-off on the suction-

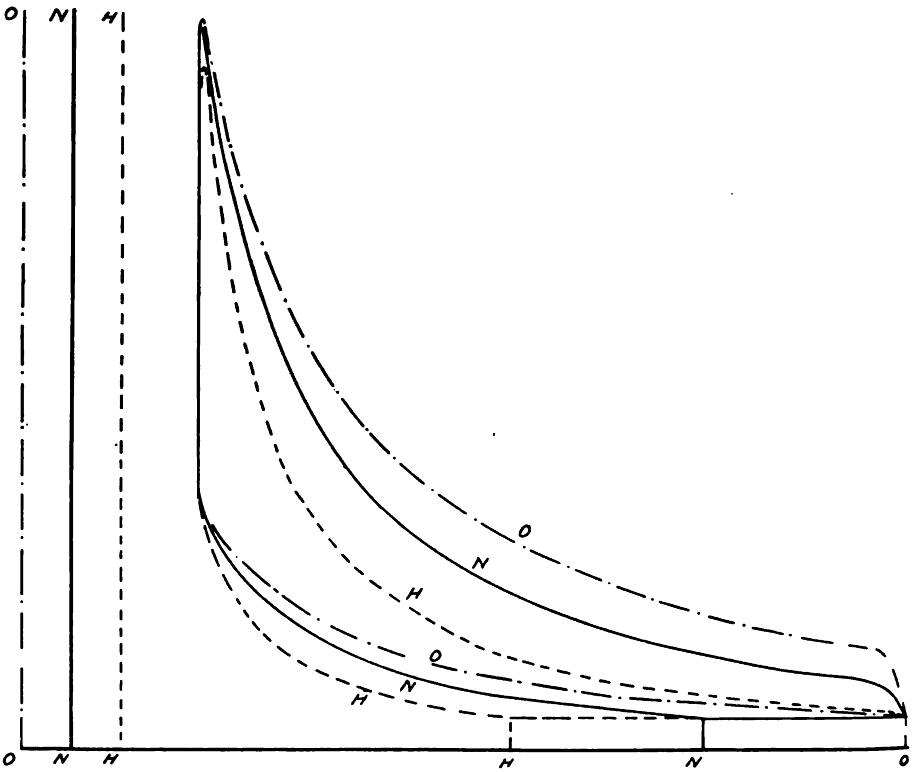

FIG. 4 GOVERNING BY VARIABLE CUT-OFF, WITH CLEARANCE VARIED TO CORRESPOND

troke. Curve A_L is the same curve laid off to the horizontal scale of rated powers of Fig. 5. Curve V shows the actual brake-efficiency to be expected from our hypothetical variable-clearance engine, upon the supposition that at the same point of cut-off (*m*) which denotes the maximum cut-off for the existing engine it possesses the same efficiency; which assumption seems reasonable. Curve V refers to both horizontal scales simultaneously; in fact, it determines the new power-scale of Fig. 5 which effects the distortion of curve A of Fig. 3 into Curve A_L of Fig. 5.

40 To explain, the existing engine which has been taken as a standard of comparison has its latest cut off at about 72 per cent of the suction stroke, and at that cut off develops its best brake efficiency of 26 per cent. At that cut off it exerts a power which is 17 per cent above the arbitrary rating which was assigned to it by its builders. These points are to be seen on the diagram by following up from point 72 on the scale of cut offs till the extremity of curve A_C is reached. Following horizontally to the right, this same efficiency is found to prevail in curve A_L at point 117 of the load-scale.

41 This point *m* represents the best that the existing engine can do. It may not take on a later cut-off than 72 per cent, in order to

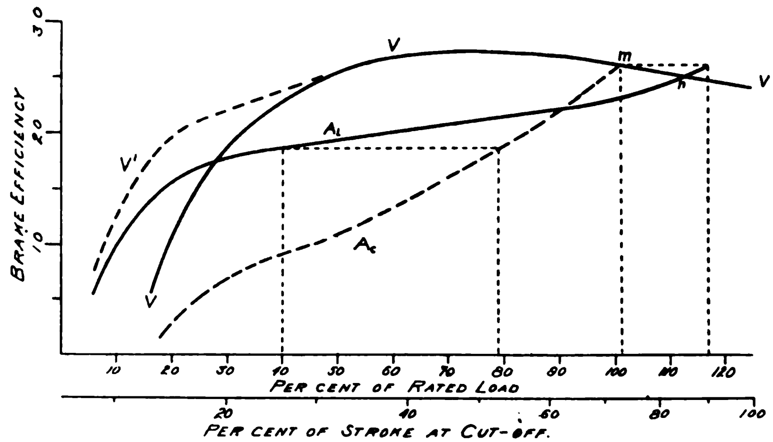

FIG. 5 EFFICIENCY-CURVES FOR ENGINES OF FIG. 4

expand its range of maximum power, or there will arise danger of pre-ignition from overcompression. It may not increase its rather small clearance in order to avoid this trouble, or it will reduce its compression and efficiency at all loads below point 117. It may not arbitrarily increase its power rating, in order to improve its efficiency at any stated fractional load, without losing its margin of power above its rating, which at 17 per cent is already too small. It may not arbitrarily decrease its rating, in order to enlarge its margin of power, without leading to its habitual use at loads so small as to ruin its average efficiency, while at the same time making it a very expensive engine in first cost per horse power.

42 In order to make the comparison between the existing and the hypothetical variable clearance engine as fair as possible, therefore,

it is assumed that the new engine, when cutting off at 72 per cent of stroke, has the same clearance, the same compression, the same efficiency and the same power as the existing engine; but that power, instead of being called 17 per cent above rated power, as in the existing engine, is called virtually rated power, or 100 per cent on the power scale (the diagram shows it as 101 per cent). This seems to be as fair an assumption for an unbuilt engine as one may make.

43 In the variable clearance engine there is no objection to using a later cut off, if the load calls for it; for overcompression will be avoided by the automatic increase of the clearance with the cut off as is shown by the change from diagram *N* to diagram *O* in Fig. 4. By the time that cut off has been extended to full stroke (100 per cent on the cut off scale) the efficiency will have fallen from 26 to 24 per cent and the power will have increased to 25 per cent above normal rating—a margin of power which, I believe, no gas engine has yet offered to the market, at least without some of the arbitrary penalties described above and which do not apply here. If the cut off be shortened below 72 per cent there is now no loss of compression to vitiate the efficiency. At 50 per cent cut off, for instance, the power has fallen to 55 per cent of normal and the efficiency has risen to over 27 per cent instead of falling.

44 It is the load scale, of course, which is of sole interest to the gas engine user. The cut off scale is a guide merely to the gas-engine builder. The latter, indeed, is introduced in the diagram only as a necessary means of stepping from one type of engine to the other. The existing engine has a relation of power to cut off quite different from that shown by the superposition of the two horizontal scales of the diagram, which gives, instead, the relation of power to cut off for the variable clearance engine. Thus, the existing engine develops 40 per cent of its rated load at a cut off of about 53 per cent, where it gives an efficiency of 18.5 per cent. The variable clearance engine, in order to develop 40 per cent of its rated power, must have a cut off of 25 per cent, and would then develop an efficiency of 22.7 per cent; or, if run at 53 per cent cut off, like the existing engine, it would develop 79 per cent of its rated power at an efficiency of 27 per cent.

45 It is to be remembered here that curve V is more or less academic in its character. While the influence of such phenomena as delayed combustion, etc., would not affect its form as markedly as they would the characteristic of a constant clearance engine, yet there would be a tendency to its distortion toward an increase of efficiency at the shorter cut offs. Moreover, while it may be possible to control the clearance space of an explosive engine through a

moderate range, it will develop, as the investigation proceeds, that there is no hope of adjusting it down to proportionality with the shorter cut offs. After the clearance, together with the cut off, has been reduced to a certain point, they can be reduced no further. From this point down to still smaller loads the engine must regulate as a constant clearance machine, with a curve like A_L of Fig. 5 in form, but probably higher. Curve *V* would probably be varied into some such form as V′ at the shorter cut offs.

46 The gain which has been accomplished by the variation of the clearance is evident at a glance. It lies in two directions:

47 First, the range of power has been extended. In the diagram the new engine apparently extends only to 25 per cent overload, while the existing engine goes to 17 per cent. But this is a referring the comparison to a quite arbitrary basis, namely, the builder's rating. A more correct statement would be that the new engine possesses its 25 per cent margin above its *natural* rating, or the point of maximum efficiency; whereas the old engine possesses no margin at all beyond that point. Another way of stating it is that if the new engine's builder should rate his machine at 60 per cent cut off, with an efficiency of over 27 per cent, he would get a margin of power above rating of 42 per cent; whereas if the existing engine's builder should rate it at such a point that it would possess a margin of 42 per cent overload, he must incur an efficiency at rated load of only 20 per cent, or a fifth less than his engine is really capable of doing.

48 Secondly, there is a great gain in *average* efficiency, although the efficiency at 72 per cent cut off is the same for the two engines. Assuming that an ordinary load will fluctuate evenly from 40 to 100 per cent of rated load, the old engine's efficiency averages at 20.7 per cent, whereas that of the new engine is 26.1 per cent, or a gain of over one-quarter. Should the load range similarly, from 30 to 115 per cent of the rating, the two efficiencies will be 21.1 and 25.3 per cent respectively, or a gain of one-fifth.

49 These gains are substantial ones. They are undoubtedly worth the seeking, although the obstacles in the way appear to be stupendous. To vary the clearance space, under governor control, of a cylinder subject to pressures ranging upward to 400 pounds per square inch is no easy task. Nevertheless, the situation is not without hope. Three general lines of solution are open to the adventurous designer. Two of these rely upon, as the means for varying the clearance space, either

a Mechanism, or

b Water pockets

respectively. The third is an indirect means for accomplishing the same end and will be treated later under the head of Outside Compression.

50 *a Mechanism:* This method would most naturally start, in its conception, with a movable head to the cylinder of an ordinary gas-engine, sliding as a piston in a continuation of the cylinder bore. Such a sliding head must be controlled by means capable of withstanding a total pressure of 400 pounds per square inch. Two such means are standard devices in the arts, viz: the screw, and the hydraulic cylinder.

51 As to the screw, although cumbrous in appearance, it is not out of the question. A diameter at the bottom of its threads of one-fifth the cylinder diameter would place its metal under a stress which is within the limits. For its operation there would naturally be provided a rotating nut held in thrust bearings, the nut being itself in the form of a worm wheel driven by a tangential worm. A second worm-drive applied to this main worm would probably provide that slowness and elasticity of drive which is requisite for success. For it is obvious that the clearance piston screw and nut will be bound and immovable in their bearings during the brief period of the heaviest pressures, whereas they will move with merely frictional resistance during the idle strokes of the main piston. Somewhere in the driving mechanism, therefore, must be provided an elasticity which will permit the heavy nut to stop for an instant while the driving end of the mechanism continues steadily in motion, without a break.

52 It has been computed that such a gear would be practicably slow and elastic if it should move the clearance-piston from maximum to minimum clearance, or the reverse, in two or three minutes. For any ordinary fluctuations in load this would be amply fast. All that is wanted usually is an adjustment of the clearance into correspondence with the average load of the period. For, it may be necessary to explain, the clearance-variation is not a means of regulation of engine-power and speed at all. The governor will be at work as usual. It aims merely to elevate the average efficiency and to extend the range of extreme power, by proportioning itself to the prevailing load in a general way.

53 As to the means for guiding this clearance control mechanism, the first thought might be that its connection with the governor were the proper thing, that the clearance might be proportional always to the cut off. Second thought, however, shows this plan to be full of peril. The desired result would be obtained only when the relation between the position of the governor for the moment and the resultant

position of the clearance piston were just right. The question of the relative adjustment between the two would be an unending source of trouble after the engine had once left the factory and its friends.

54 Third thought on this question returns to the original object of the entire enterprise, viz: the maintenance of compression and explosion pressures virtually constant. Let, then, a certain maximum explosion pressure be chosen, say 350 pounds. Let the cylinder be equipped with a tiny safety valve set to blow off at this pressure. Let the discharge from this safety valve be utilized to operate a piston or diafram, to throw into or out of gear a small friction clutch in the train of mechanism between main shaft and clearance screw. Plenty of power is available. Since the motion of the clearance piston is very slow and its resistance (when it will move at all) merely frictional, friction gearing ought to suffice for this job. The clearance piston will then creep slowly in or out, following the general fluctuations of load, so as to keep explosion pressures very nearly at the chosen point.

55 The above supposition is described in detail merely to illustrate the statement that the variation of the clearance is a problem embodying its solution automatically in its premises. It is the heavy pressures which it is aimed to control which themselves supply power requisite for the task. This fact will be seen to underlie all of the diverse methods suggested herein toward a solution.

56 It may be questioned as to whether this constancy of explosion pressures, even if attained, were desirable. On short cut offs the excessive cooling surface in proportion to the charge, together with the greater likelihood of dilution with burnt gases, would naturally lead to lower temperatures and pressures developing from a given compression pressure. If so, then our projected device would call for higher compression on the lighter loads and vice versa, or an overadjustment of clearance space to load. For myself, I can see no objection to this. It should improve the form of the engine's characteristic, rather than the opposite. Moreover, it is to be remembered that it will be impossible to reduce the clearance by any movable head or its equivalent to a lower percentage than about seven, corresponding to about forty-five per cent of rated load. At loads smaller than that the clearance variator will go out of commission, and the governor will then control the power quite as at present except that the now constant clearance is unusually small. The likelihood is that the engine's characteristic will be altered from the theoretic curve VV of Fig. 5 to VV'. That is to say, at these very short cut-offs the presence of surplus clearance filled with burnt gases, leading to

slower combustion and lower and later maximum pressures, would be beneficial rather than otherwise; for the prime reason for the rapid drop of the curve VV at the shorter cut offs is the over expansion of the hot charge below atmospheric pressure at the latter end of the stroke, because of the very small clearance needed to keep the theoretic pressure of explosion up to the predetermined point.

57 Some of the considerations just listed were brought to light during the study of designs of several forms of engine of this type which were undertaken by Messrs. H. E. Harvey, C. A. Merritt and Phillip L. Sibley in 1904, whose assistance in this connection I desire to acknowledge.

58 *b* The *hydraulic cylinder* as a means of clearance control might be used for the operation of the movable piston head much as it was proposed to use the screw. Since there is plenty of motive power within the engine cylinder to move the clearance piston outwardly, the hydraulic cylinder need be only single acting, containing a plunger attached directly to the clearance piston. A little pump on the engine would keep a hydraulic accumulator charged. The diaphragm operated by the little safety valve would then have only to operate a three-way cock, letting water from the accumulator into and out of the hydraulic cylinder. The accumulator pressure need be only enough to overcome the frictional resistance of the clearance piston with certainty for during the explosion the latter could settle back upon the water, which would be held by check valves, without harm; when the exhaust valve opened it would resume its inward motion, if such were needed. Such an arrangement would be far superior to the screw and worm, both in its simplicity and in the speed with which it would be practicable to operate it.

59 A slight modification of this proposal brings it into even greater simplicity. Let it be imagined that the hydraulic accumulator is set to the pressure which, taken for the area of the plunger, is the equivalent of the engine's mean effective pressure on the area of the main piston. Let the plunger be connected to the automatic controller of the accumulator pressure, so that when the plunger stands for minimum clearance the accumulator pressure will be at its least, and vice versa. Let the connection between the accumulator and the hydraulic cylinder be always wide open, without diaphragms, cocks, etc., but let it be very small—a mere leak.

60 The plunger, with the clearance-piston attached, will now act as a mean pressure indicator for the interior of the cylinder. During those portions of the engine's cycle when gaseous cylinder pressures are higher than their mean, they will overcome the hydraulic pressure

and drive some water back into the accumulator, increasing the engine clearance; but the displacement would be very slight. During the remainder of the cycle the accumulator pressure would overcome the resistance of the clearance piston and slightly reduce the clearance. The balance of these positive and negative displacements of each cycle would determine the adjustment of the clearance, increasingly or decreasingly. Under heavy mean effective pressures in the engine cylinder the clearance would be large; under lighter powers it would be small. The adjustment of the average accumulator pressure gives a ready control of the maximum pressures desired to be maintained as standard within the engine.

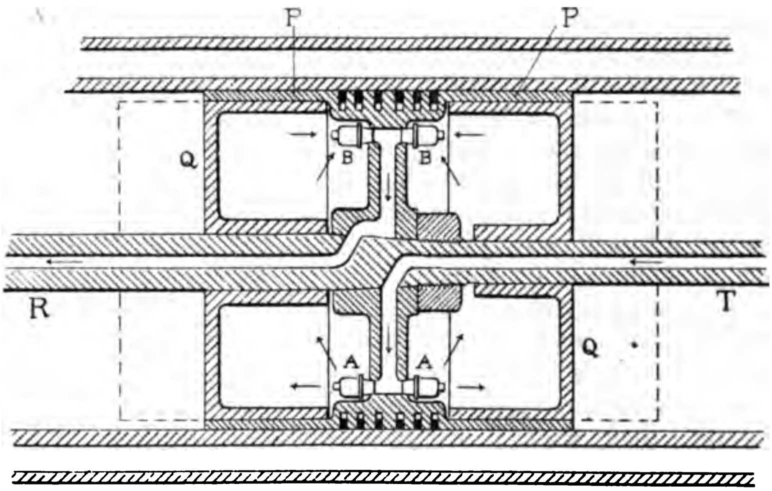

FIG. 6 CLEARANCE-VARIATION BY EXPANSIBLE PISTON

61 There is imaginable, however, still another suggestion for a hydraulic control of clearances, which may be better yet. All large double acting gas engines are equipped with a water circulation through the piston-rod, piston and tail rod. If this circulation system be utilized to carry hydraulic power to clearance pistons situated directly on the face of the main piston, the cylinder heads will be left undisturbed and free for the best arrangement of valves, igniters, etc., as at present. Such an arrangement is shown diagrammatically in Fig. 6. It portrays the jacketed main cylinder and heads of a horizontal double-acting gas engine, all valves, etc., being omitted from the sketch. The main piston *PP* is shown, attached to the piston rod *R* and the tail rod *T*, both of which are hollow. The main

piston structure is equipped with two followers QQ which are long enough and work freely enough within the main piston to act as clearance pistons. When these followers are in their innermost positions, as drawn, the engine's clearance spaces are at their maximum; their distention to the positions shown in dotted lines reduces the clearance to a minimum. For their actuation the tail rod brings in water from an accumulator under merely sufficient pressure to overcome the friction of the followers in the main piston, in which they work with a merely water-packed joint. This water finds access to the piston body through the spring check valves AA. The spring check valves BB permit the egress of this water through the piston rod R. The latter may be loaded to a resistance equal to the desired explosion pressure or, what is better, they may open freely, while the desired resistance is imposed upon the exit conduit outside the cylinder, where it is accessible for adjustment.

62 In operation, a little water will enter from the accumulator and distend the piston slightly during each suction stroke of the engine, until the resultant decrease of the clearance so crowds up the explosion pressure that an equal amount of water is driven out through BB each cycle. The amount of water admitted each cycle will be determined by the set of the admission cock. When the governor opens up a long cut off on the suction stroke and produces a heavy explosion more water than this will be driven out each cycle and the clearance will grow into correspondence with the cut off. When the governor reduces the cut off and the violence of the impulse, less water than this, or possibly none at all, will be driven out each cycle, and the piston will slowly distend until clearances are properly reduced.

63 As to constructive difficulties which may be foreseen, the most obvious one is the leakage of water past the followers. Yet, if it be remembered that the gaseous pressure within the cylinder, which alone places the water under stress, is also exerted at the joints between piston and follower, forcing the water back through this joint as forcibly as it squeezes it out, it will be seen that the only tendency to leakage is that due to the gravity of the water itself; which ought to be controllable with comparatively easy fits between piston and follower.

64 *c* Variation of clearance by *water pockets.* It is in this class of clearance-variators that is found the only instance of the actual construction of a variable clearance engine known to the writer. This is the engine exhibited in London in 1903 by Mr. Adolph Vogt, and illustrated and described in London "Engineering" of January 8, 1904.

For convenience, a diagram showing the general idea underlying its design is reproduced in Fig. 7. The engine's operation relies upon the interposition of a body of water between the piston proper and the explosion. As the piston reciprocates, the surfaces of the two bodies of water, at head and crank ends of the cylinder respectively, move up and down alternately. Above them are formed the explosion chambers, equipped with the usual igniters and valves. In such an engine any variation in the quantity of water on hand obviously varies the effective clearance. The means already suggested for the hydraulic control of clearance might be applied directly to these

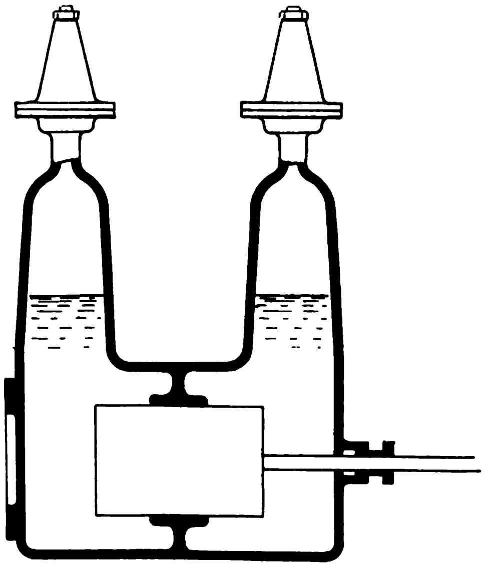

FIG. 7 CLEARANCE-VARIATION BY WATER-POCKETS IN CYLINDER

water chambers, instead of to the hydraulic cylinder. I believe, however, that no automatic control of the clearances has yet been applied to this engine.

65 Such an engine as the above would plainly be limited narrowly as to its speed. Any attempt at a high piston speed would not only develop abnormal inertia effects in the mass of water present, but it would so disturb the surface of the water as to seriously affect, if not destroy, the explosive action. As a riddance of this trouble the writer has suggested (previously to the appearance of Mr. Vogt's engine) a form of engine quite like Mr. Vogt's, but turned the other side up, with the two horns of the cylinder turned down and become

water pockets. In such an engine only the piston would move, while the water remained at rest at the bottom of the pockets. The valves and igniters would of course be removed above the surface of the water. He has also suggested one or two forms of outside-compression engines (that is to say, engines having the compression performed completely in a cylinder separate from the explosion-cylinder) in which the clearance spaces of both the exploder or motor cylinder and of the compression-cylinder were in the form of pockets containing water.

66 But against all of these plans for the presence of a body of water within the explosion cylinder, against the surface of which the explosion is to occur, there is to be urged a general objection which may be overwhelming. It is to be remembered that in the Otto type gas engine the storage of heat in the walls by the working charge is as beneficial as in the steam engine it is harmful. During the first period of combustion the cylinder walls absorb heat which must otherwise be wasted, because of its intolerable temperature; and later in the expansion stroke the working gases rely considerably upon this stored high temperature heat for their support.[1] This action is a fundamental factor in the efficiency of the engine; but it would be quite impossible of occurrence with the water surfaces suggested.

67 This, so far as the writer is aware, exhausts the list of general methods proposed for the actual variation and control of clearance, although many minor modifications may be found. The next method in order for consideration is one which varies the clearance only in effect, instead of literally; but its results offer a wider promise than do any of the preceding plans. This method is that of the use of outside compression.

OUTSIDE COMPRESSION

68 Imagine a gas engine consisting of at least two cylinders, one devoted solely to compression and the other solely to combustion and expansion. The compressor would most naturally be double acting. The exploder might also be double acting; or two single acting exploders might be fed by one double acting compressor.

69 Here, to forestall misunderstanding, we insert a parenthesis to the effect that the machine in mind is not the ordinary two-cycle or Clerk-cycle engine, which performs only a little compression in the feeding-cylinder—only enough to blow the gases into the motor-

[1] See the writer's "Entropy-analysis of the Otto Cycle," Trans. Am.Soc.M.E. 1903, and his "Thermodynamics of Heat-engines," page 300.

cylinder—and then loses it all when the transfer takes place; for such an engine finally performs all of the compression in the exploder. In the proposed engine the compressing cylinder is to discharge the fuel and air into the explosion cylinder at the full pressure predetermined as the one fit for ignition and explosion to take place.

70 Nor, this being the case, is the new engine to burn the charge continuously at constant pressure, either between the cylinders or as it enters the motor cylinder, as was the case in the old Brayton engine. The new engine is to transfer its charge of gas and air, fully compressed, and the two preferably compressed separately, from compressor to motor cylinder unignited. After a suitable portion of

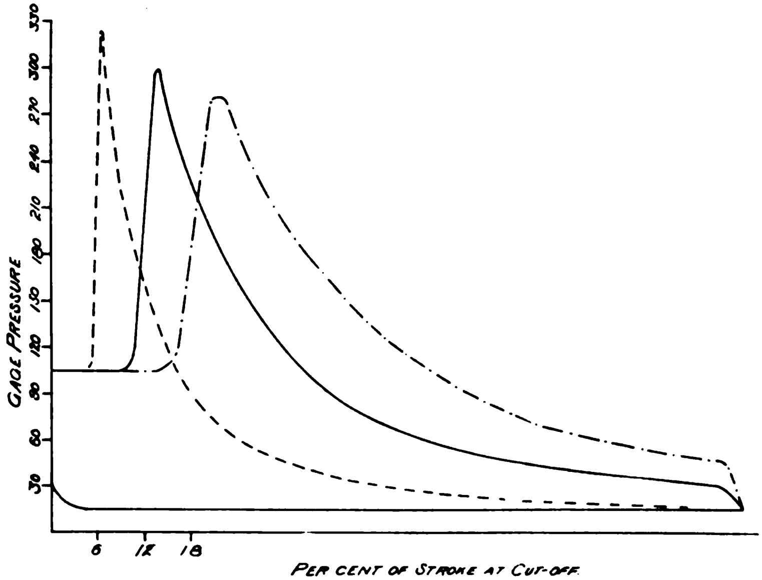

FIG. 8 GOVERNING BY VARIABLE CUT-OFF UNDER CONSTANT COMPRESSION IN SEPARATE CYLINDER

explosive mixture has been taken into the motor cylinder, the supply is cut off and is simultaneously ignited. Explosive combustion at nominally constant volume then ensues, although the piston is really in motion, and after that expansion may proceed as in any engine, to any predetermined degree; the latter, as in the steam engine, depending, only on the cut off.

71 The theoretic indicator-card developed by such an engine, under different loads, is shown in Fig. 8. The full line card is supposedly that at normal load, the broken line card one at fractional load and the broken and dotted card one under overload.

72 It will be noticed that such an engine would be working upon what is virtually a Lenoir cycle operated at high pressure. Now the old Lenoir cycle was in several respects the best cycle which we have yet had before us. It gives an impulse at each stroke, yet with none of the doubt as to the mixing of fresh charge with burnt gases which is incidental to the hurried "change cars" of the two cycle Otto engine. It permits the governor to decide as to the energy of each impulse *after the engine stroke for that impulse has already begun*; which we found to be one of the marked lacks in the existing gas engine. It permits any desired degree of expansion to be attained, without incidental variation in the degree of compression (if there be any), which is another marked lack in existing engines. It will be seen shortly that if it be equipped with this outside compression it also lends itself easily to the duties of a reversing engine, which is a third impossibility with existing engines. The only thing which was wrong with the Lenoir cycle was its inefficiency due to lack of compression—which lack we now propose to make good—and its overheating, which modern methods of design can now take care of.

73 As to the probable efficiency of such a "high-pressure Lenoir" engine as has just been proposed, a short investigation of its probable variation with the change of load, so far as it may be revealed by such diagrams as those of Fig. 8, shows it to be characterized by a curve quite parallel with that of Fig. 5 labelled VV', the same as that of the variable clearance Otto engine, and quite superior to the best modern practice.

74 There is an operative limitation to the value of this new high-pressure Lenoir engine, however, which prevails quite independently of its glittering promise in the direction of efficiency. This is its limit in practicable speed. It is obvious that the period of time available for closing the admission valve and igniting and fully burning the charge, in such a way as to have the combustion occur explosively, in spite of the fact that the piston is in motion with mid stroke velocity, demands great rapidity in the performance of these events. The situation demands some ingenuity in the gear for carrying out these functions, and at the best a moderate speed of rotation for the engine.

75 As to the gear needful for performing the causative part of the task, it is thought that that can be supplied by proceeding upon the plan of igniting while the charge is still flowing freely in through the admission valve, and then arranging to have the ensuing explosion close the valve. Such a procedure eliminates the serious problem of how to keep always in proper adjustment the relative timing of cut

off and ignition, if both were to be left to mechanical causation. Yet a limitation of the speed of rotation below that common in many types of modern gas engines would still prevail.

76 On the other hand, there are many services in which this limitation would not be a serious one. In the first place, the limitation is not in piston speed, but in rotative speed; for the period available for combustion must be small only when compared with that required for the completion of the stroke. This proclaims immediately the fitness of the cycle for large engines. And if it be urged that in the cylinders of large engines the period of inflammation is greater than in smaller ones, the natural reply is that the plan of ignition at more than one spot in the compressed charge as a means of hastening inflammation, has never yet been fully investigated, because never yet needed.

77 This new type of high pressure Lenoir, when a complete unit in itself, must always embody a compressor cylinder. This is no bar in the line of cost, because any gas engine which is to develop an impulse each revolution must possess two single acting cylinders anyhow.

78 The necessary presence of a compressor cylinder makes the high pressure Lenoir an engine preëminently adapted for blowing or compressing. For the latter service the compressor cylinder would merely be made abnormally large, to serve the double purpose of supplying its own motor cylinder and the outside mains also—so large as to absorb all of the power of the motor cylinder, leaving none for distribution by the shaft in mechanical form.

79 For the task of blowing, where the pressure of discharge is considerably below that fit for explosive combustion, the engine would be equipped with a small compressing cylinder drawing its suction from the discharge main of the blower. This would supply the motor cylinder with a charge compressed to a degree which is now impracticable because of danger from preignition. If the intercooling between blower and compressing cylinder were complete, present limits of compression could be transgressed by two or three fold without danger. Even with single-stage compression it is to be pointed out that the outside compression engine would permit a higher compression than is now safe to use; for the charge at the beginning of compression would then be at atmospheric temperature, instead of at the 120 to 150 degrees fahr. which is usual when the charge is taken into the combustion cylinder for compression.

80 It is next to be noted that it is not necessary for the compressor cylinder of the high pressure Lenoir engine to be an integral

part of the machine which carries the mechanical load. A single central compressing cylinder may feed, through a system of mains, a dozen or more distinct and separate engines scattered about a mill, each consisting of an explosion cylinder only. Some of these secondary engines might be used for continuous rotation at constant speed, for generating current or driving shafting. Others might be hand controlled reversing engines, actuating rolls, etc. During reversal such engines would be actuated, for a fraction of a revolution or so, solely as a compressed air motor, the fuel supply being cut off temporarily. So soon as rotation in the reversed direction had proceeded sufficiently so that any one cylinder of the engine, if it were multiple-cylinder in form, had gotten its charge of fresh explosive mixture, explosive combustion might be again relied upon as the source of power. The possibilities of this system of gas engine design for steel mill drives, where compressed air, electricity and reversible roll drives are all needed and where cheap gas is usually available, appears to be enormous.

81 Nor is it necessary to have the engine divested of its compressor in order to have it reversible. If the compressor were fitted with automatic valves it would operate equally well with the shaft rotating in either direction.

82 This type of engine and its cycle have been foreshadowed by a number of inventors. Their patents, however, are vague and inaccurate in their statement of the results to be attained, the difficulties involved and the method of their surmounting, although they describe in each case a mechanism which, if run slowly enough, would develop this high-pressure Lenoir cycle. They quite fail, too, to indicate the possibilities of the engine when properly worked up into a system of mill-power, with its units specially designed to attain a proper piston speed. Some of these patents concern the application of the cycle to automobile service, for which it is manifestly unfit because of its fundamental limitation in speed of rotation.

83 It is sufficient to the title of the present article to have pointed out at least one non-existent type of gas engine which is hardly more than a modification of the existing Otto type engine and which is yet capable of as delicate regulation, and by the same means, as is the steam engine. It is of an additional interest which is by no means merely incidental that such a gas engine would also possess, alone of all existing gas engines, a characteristic curve of efficiency similar in form to that of the steam-engine, and an ability to transmit and subdivide power for various purposes which is neither exceeded nor equalled by the steam-engine.

The Joule Cycle, and Combustion under Constant Pressure

84 All existing gas or oil engines except the Brayton, the Diesel, the Gardie and perhaps a few others of less importance, and all the hypothetical engines hitherto discussed in these pages, have relied upon combustion at virtually constant volume, with pressures rising in explosive fashion, for their motive heat. Contrasted with this, however there is another method of combustion which has long been before the public in one form or another and which has always attracted a large number of inventors. This other method relies upon combustion under constant pressure, with an increase of volume only, rather than upon combustion under constant volume with increasing pressure.

85 I do not know the complete history of this general idea. So long ago as 1807 such an engine was proposed by Sir George Cayley,[1] and was afterwards developed by Wenham and Buckett, in England. This engine used an enclosed furnace containing a coal fire, through which compressed air was forced in a quiet current. In passing through the fire the air became heated by its own combustion and expanded in volume. The products of combustion passed from the furnace into an expansion or motor cylinder, where they developed more power than was absorbed in their compression. The net difference was available for outside work.

86 Later in the nineteenth century Joule is said to have proposed quite independently, the cycle consisting of these four processes, namely:

a The compression of atmospheric air;

b Its heating under constant pressure with increasing volume;

c Its expansion in a motor cylinder larger than the compressor;

d Its exhaust to the atmosphere for condensation.

This cycle contemplated the transmission of the heat through the envelop of the working air, as was done in the Stirling and Ericsson hot air engines, instead of the development of the heat by internal combustion.

87 It is doubtful if Joule deserves the credit of having the general constant pressure cycle named for him; but for want of a more just appellation, we shall here call it the Joule cycle.

88 Yet, in spite of this long continued interest in the general plan, there is today no representative of it successful upon the market. The Brayton, although temporarily quite popular, could not compete

[1] See Ewing's "The Steam Engine," page 365

with the Otto engine which appeared in 1876. The Gardie, a French engine using a gas producer under pressure between the compressor and the expander, is considerably advertised abroad, but has failed in at least one attempt to enter this country. There is no other representative of the type which has attained to even this degree of commercial prominence.

89 The Diesel motor is sometimes spoken of as such, but it is not. There is some combustion under virtually constant pressure incidental to its action, but that is later vitiated by combustion "under constant temperature;" and the machine is so special in its manner of ignition and its range of pressure that it possesses less of the characteristics which are naturally attendant upon continuous combustion under constant pressure than does almost any other engine. Indeed except for features of advantage and disadvantage connected solely with the question of fuel used, the Diesel stands as an extreme and special high pressure development of the Otto type, rather than as a first step toward the broad development of the gas engine toward a type similar to the steam engine.[1]

90 It may be said broadly, therefore, that we now have upon the market no successful representative of this broad class of gas and oil engines. It is proper to inquire, first, why we should expect to have one, and secondly, why we have none.

91 In answer to the first query, imagine the mechanical combination illustrated diagrammatically in Fig. 9. A compressor or compressors feed air and fuel into a closed system leading to a heat insulated furnace, and beyond the furnace is an expansion cylinder driving both the compressors and the shaft. Therein, *C* is the compressor, *F* the enclosed furnace, *M* the motor cylinder and *S* the driven shaft. *R* is a reservoir of considerable volume, which may or may not be included in the system. For the present all questions of construction, durability, etc., will be neglected.

92 In such a system the valuable features arise from the ease with which the power may be varied, either in quantity, speed or direction of rotation, without appreciable effect upon the perfection of combustion occurring within *F*. *F* is white hot inside, instead of

[1] The writer has long taught his students that the remarkable efficiency of the Diesel engine could be closely paralleled by any designer of Otto engines who chose to incur similarly high pressures. Since these pages were written a preliminary report from Professor Burstall, of the Gas Engine Research Committee of the British Institution of Mechanical Engineers, tells of an indicated efficiency of over 41 per cent gotten from a very small Otto engine by using a compression of 200 pounds. This he calls "Diesel efficiency."

being water jacketed, so that poor mixtures of fuel and air may not get through unburned. It has no rapidly moving piston to determine how fast the combustion must proceed in order to be useful. The current of combustible fluids may pass through F fast or slowly, provided its capacity be not exceeded, and in lean or rich mixture; yet the heat will always be developed. Then, too, the action in F is unconscious of whether S be rotated in one direction or the other. A given volume of fluids may be passed through F by a small high speed machine or a large slow speed one, or the compressor may be of one type while the expander is of another. Indeed, the compressor and expander are not necessarily parts of the same machine. Yet practice shows the combustion to be unaffected. It may be said, in general, that continuous flame combustion takes place much more readily under high pressure than under atmospheric pressure.

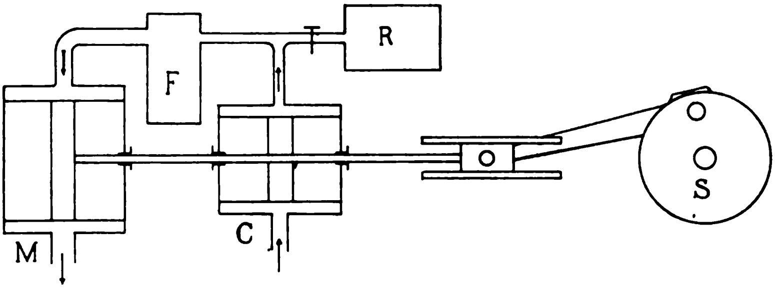

FIG. 9 ENGINE FOR COMBUSTION UNDER CONSTANT PRESSURE

93 Let us suppose, now, that cylinder M normally develops 167 horse power. Normally about four-tenths of this, or 67 horse power, would be absorbed in compression, leaving a net 100 horse power for the shaft S. If the governor of the machine is able to vary the power of M, in steam engine fashion, from zero to twenty per cent above its rating, then, as it did so, the net power of the machine would vary as follows:

MOTOR'S POWER	COMPRESSOR'S RESISTANCE	NET POWER DELIVERED TO SHAFT
Horse power	Horse power	h. p. and per cent of rating
200	67	133
167	67	100
133	67	66
100	67	33
67	67	0
33	67	−34
0	67	−67

94 Of course, the figures in the last column above zero and below the maximum imply the presence of some means for by-passing the unneeded air around the furnace, which is easily done. Those below zero imply the storage of compressed fluids in the reservoir, which could not continue indefinitely; yet for temporary purposes it would be of great use. The machine therefore possesses a wider range of power than even the steam-engine. Its regulation, too, would be exactly that of a steam engine, both in promptness and in delicacy.

Why, then, has no engine of this type succeeded?

95 First, as to efficiency. The efficiencies of the constant-pressure and the Otto cycles are *theoretically* the same at the same degree of compression. It is this fact which has led all the earlier constructors in this novel field, down to the present time so far as I know, to adopt the same degree of compression as that prevailing in the Otto type engines of their day, usually six to eight atmospheres. But it is a striking characteristic of the constant pressure type that its "fixed charges" of frictional and thermal loss, and especially the former, are much greater than those of the Otto type. The proportion of the gross power developed in the motor cylinder which is needed for compression is much larger than in the Otto type, being some forty or fifty per cent as compared with twenty or twenty-five for the latter. This resistance is fully included in computing the theoretic indicated efficiency, but its incidental friction and commercial cost are not. Just as the Otto type, with its moderate proportion of compression, has a much poorer mechanical efficiency than the steam engine, which has no compression of its fuel and air at all, so the Joule type, with its magnified amount of compression, has a mechanical efficiency still poorer than the Otto.

96 In addition to this greater proportion of power going to compression, the surface swept over by the pistons of a Joule type engine, per unit of power developed, is much greater than in the Otto. Fig. 10 is designed to show this. In Fig, 10 *ABCDEFB* is the indicator-card of an Otto engine. *MBCNM* is the card of the compressor cylinder, and *MNOSTM* is the card of the motor cylinder, of an equivalent Joule type engine. The distance traversed by a piston of any given diameter, in developing work from a given amount of fuel at a given degree of compression in the two cycles respectively, is that measured by twice the distance *AB* for the Otto cycle and *MB* plus *MT* for the Joule, or in the proportion of two to three.

97 It is the two obstacles of friction and cost involved in this unusual transmission of power from motor to compressor, and of fluids from compressor to motor, which have always kept the constant

pressure engine out of use. No machine of that type may hope to succeed which does not transmit the power needed for compression directly from the motor piston, without transfer through oblique rods, slides and cranks, or to a fly wheel and back again. As a resultant of this, also, no machine of that type which does not carry its compression very much higher than that customary in the Otto type, so as to develop an indicated efficiency so high that it can afford these losses just mentioned, may hope to compete.

98 Yet there is hope even here. In the Joule cycle compression is not limited by anything like the narrow bounds which confine it in thé Otto. In the latter the maximum pressure which the mechan-

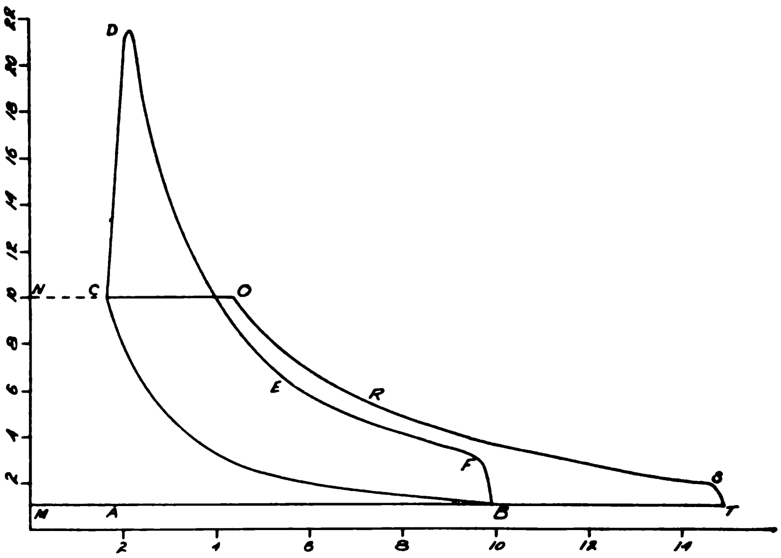

FIG. 10 OTTO-CYCLE AND JOULE-CYCLE DIAGRAMS

ism must stand is, upon occasion, three or four times the compression pressure; while in the Joule engine it is merely the compression pressure itself. This being so, it might seem impartial to the two types to compare them with their maximum pressures, rather than with their compression pressures, alike. If we do this we must have the Joule cycle compressing to some 350 pounds per square inch, or about twenty-five atmospheres, and burning at that pressure. Its theoretic efficiency would then be a third better than it was when compressing to only eight atmospheres.

99 With this gain in theoretic possibilities the Joule cycle has some chance for successful competition. It has been the experience

of both myself and others, so far as I am acquainted, that a working-pressure of at least five atmospheres must be attained before a Joule engine has any likelihood of being able to develop enough net power to overcome even its own resistance; but from that pressure upwards the gain of power and efficiency with increase of pressure is rapid. The "fixed charges," both thermal and frictional, have then been met. Nearly all the increase in theoretic power due to the increase in pressure is available as actual power.

100 That is to say, the theoretic efficiency of the Otto engine compressing to eight atmospheres is about 45 per cent, of which about one-half, or 23 per cent, is actually available on the shaft. The theoretic efficiency of the Joule engine compressing to five atmospheres is about 37 per cent, none of which is available at the shaft. But when compressing to twenty-five atmospheres the theoretic efficiency of the Joule engine is about 60 per cent. If we now deduct the losses incurred at five atmospheres, which have not been appreciably increased by the rise in pressure, the net result is 23 per cent, or about on a par with the Otto type. The maximum pressures of the two engines are also about equal. So the two cycles are about equal in efficiency when worked to the same maximum pressures. Comparative superiority, therefore, must be fought out between them along considerations which are purely mechanical or commercial in their nature.

101 But here arises a fresh obstacle. Generations of experience with steam engines has taught us that the piston and cylinder may not be used profitably for so wide a range of pressure as from one to twenty-five atmospheres. If greater ranges of pressure than that are to be used compounding must be resorted to.

102 To be sure, the Otto type of gas engine starts its expansion at a pressure of twenty-five atmospheres and incurs atmospheric pressure on the back stroke; but it gives up further expansion when a pressure of three or four atmospheres is reached. The Diesel comes nearer to doing it, for it starts its expansion at nearly forty atmospheres and stops at only two or three. Both machines handle atmospheric pressure during their suction stroke. Both of them, too, pay heavily for their infraction of this fundamental rule in engine design, in their excessive first cost and uncontrollability as compared with the steam engine.

103 Now it is only by its promise of approach to steam engine standards that the Joule cycle holds forth any inducement to patronage. Therefore, if it is to work successfully to twenty-five atmospheres it must be compounded on both the compression and the

expansion side. To supply compounding on the compression side is easy—easier than to withhold it, at twenty-five atmospheres. But compounding on the expansion side is another and a much more difficult matter. Apparently no person has ever yet succeeded in expanding the products of internal combustion through two stages or cylinders, and in deriving any decent proportion of the power theoretically to be expected from the second stage. The best which has been accomplished has been to get the low-pressure piston to overcome its own friction, and sometimes not even that.

104 The reasons for this are explainable by the same phenomena which were referred to in connection with the unfitness of water for direct contact with the working gases of an explosion engine, namely, the very rapid heat interchange which takes place with the envelop when these very hot gases are concerned, and the extreme sensitiveness of their particular form of heat motive power to the abstraction of heat. The heat stored in the walls by the flame in the locality of combusition is a marked source of power in the ordinary or non-compound Otto type gas engine. Its lack in the low pressure cylinder of a compound explosion engine is the source of the chill which is always revealed by the collapse of the gases as they enter this cylinder in such engines. The discussion of this phenomenon, in its general bearing upon the problem of compounding an internal combustion engine, amounts to saying that the dry working gases of such an engine possess too much temperature and *too little entropy*, or heat mass, to stand up for themselves when transferred from the place of their birth to a strange locality. In order to solve the problem we must give to the working substance enough entropy to give it carrying power.

105 Now a decrease in temperature and an increase in entropy is the easiest thing in the world to accomplish. It is an incident to every instance of heat conduction. Moreover, as the evaporation of water into steam involves the greatest increase of entropy of any familiar phenomenon, and the resultant temperature of the process is automatically controlled by the prevailing pressure. Let us, therefore, exchange this unstable and evanescent heat of the hot gases for stable and reliable steam heat of a lower temperature, which will carry through a succession of cylinders when the other will not. Moreover, the products of combustion are too hot to be handled efficiently in a lagged cylinder, the drop in temperature is in itself an advantage.

106 Therefore let us use the products of combustion to make steam before attempting to drive a piston with them; and since they are

already under the pressure at which the steam is to be used, their heat is most conveniently transferred to the water by actual contact. To effect this the flame may be generated upside down over water and, so soon as combustion is complete, plunged therein. Fig. 11 shows in diagram form what the furnace develops into along this line.

The question which arises as to the effect of this device is, may we expect to gain enough in availability from our gain in entropy to make up for our loss of availability in our loss of temperature?

107 I think that we may. The reasons for the belief are shown in Fig. 12. This diagram displays, first, the comparative theoretic efficiencies of the Otto and Joule cycles respectively, when both work

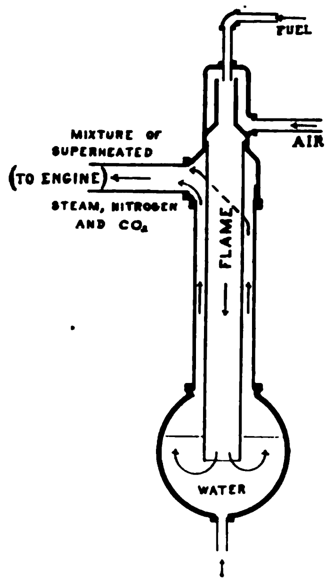

FIG. 11 DIAGRAM OF COMBUSTION-CHAMBER AND STEAM-GENERATOR FOR ENGINE OF FIG. 9

to the same maximum pressure. The Otto cycle is drawn for a compression of 103 pounds by gage, exploding to 350 pounds. The Joule compresses direct to 350 pounds. Both cycles represent the action of about one pound of working substance, receiving 1000 B.t.u. from the fuel.

108 The Joule cycle, *ACEGA*, almost completely encloses the Otto cycle *ABDFA*. But both are extremely high temperature cycles. In the Otto cycle high temperature is valuable, to a certain degree, until compounding is undertaken. Then all its value is lost. The same would apply to the Joule; but in the latter, ***compounding may never be dispensed with.*** At the same time, temperature

loss and entropy gain is possible in the Joule, while impossible in the Otto cycle.

109 Fig. 12 therefore shows, also, the conversion of the high-temperature narrow entropy heat of the Joule cycle, by means of the apparatus of Fig. 11, into the resultant low temperature wide entropy

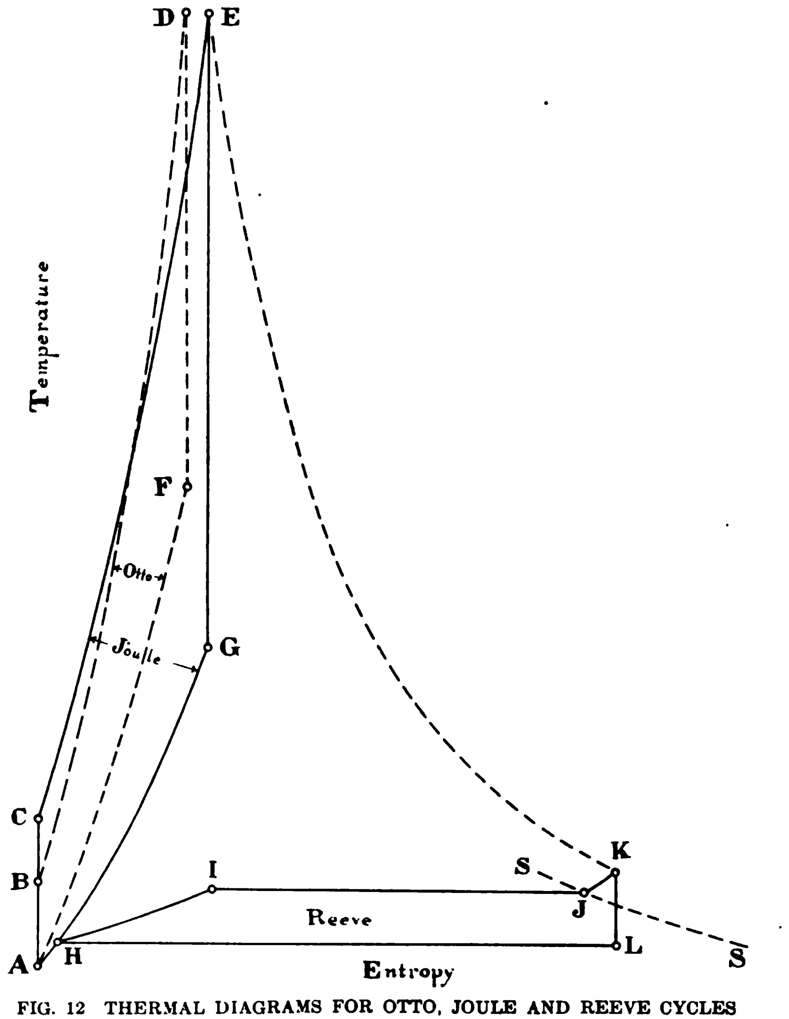

FIG. 12 THERMAL DIAGRAMS FOR OTTO, JOULE AND REEVE CYCLES

cycle *HIJKLH*, which displays the thermodynamic action of the mixture of nitrogen, carbon dioxid and superheated steam which is discharged from the generator of Fig. 11, to serve as a working substance in the expansion cylinders. That is to say, the heat exchange occurring in the generator is shown by the free fall or constant heat curve EK.

110 The tremendous reduction in the temperature drop within the engine, with its inevitable advantages and disadvantages, is visible at a glance. The point of interest is that, whereas only a fraction of either of the original cycles is actually available for work, both being subject to heavy water jacket losses inseparable from high temperatures, the reduced area of $HIJKL$ is virtually all available for work. It has neither the great temperature differences of the gas engine nor the wet steam of the saturated steam engine to promote activity of wall loss.

111 In practice, this plan fully justifies its theory. That is to say, it gains controllability and reliability; although whether at too great an expense in other directions cannot be known without lapse of time. The steam generator or cooling chamber holds the temperature of its composite discharge stable within a few degrees, under wide fluctuation in flame; yet this stable temperature is readily altered by an alteration in the water level, which is of course maintained automatically. As actually operated this temperature is most readily held at about 550 degrees fahr., a point already empirically reached in steam engine practice with superheated steam as the one most conducive to safe and efficient action within the cylinder.

112 As to compounding, the success of the principle of providing ample entropy is more striking still. The power carries over into the low pressure cylinder perfectly. This cylinder not only performs its full share of the work, but more.

113 For instance, for the purposes of adjusting the processes of combustion, our chief experimental engine was run for some time with a supply of factory steam in the low pressure cylinder, to keep the compressors in motion without relying upon the engine's own motive power. The full capacity of the compressors was then being run into the furnace, under full pressure, and burned. The furnace was white hot inside and well lagged outside. Combustion was known to be complete. Every heat unit in the normal fuel supply was being developed and thrown into the high pressure cylinder.

114 But as yet no water had been supplied to the spherical pot of Fig 11. No steam was being made. In consequence the engine showed no sign of life, when the power derived from the factory boiler was shut off, although the Joule cycle of Fig. 12 was being performed as perfectly as possible.

115 Then *cold* water was pumped into the pot, up against the down-coming flame. It would seem a most natural expectation that

under those chilling circumstances the last vestige of power developing effect from the gas flame would disappear. Yet, on the contrary, the cold water had no sooner reached the flame than the engine showed every sign of a life and power of its own, picking up speed and accumulating pressure independently of the outside power.

116 There could be no more striking illustration than this of the fact that entropy, or heat mass, is the thing about heat which is of equal avail for doing work with temperature drop; if, indeed, it be not sometimes *more* effective; just as mechanical mass is often of equal or greater avail for doing work than is velocity. For instance, when we wish to drive a pile effectively we do not take a tack hammer and give it the velocity of a rifle bullet downward on the end of the pile, in order to embody in the tack hammer the requisite amount of kinetic energy. Yet such a procedure is an accurate analogy to the use of the white-hot, but thin, molecules of the hot dry gases of a gas-engine flame, impinging against the piston with the enormous velocity of their bright heat, but with little entropy or mass, as a means for its propulsion.

117 In the case of the pile we take, instead of the tack-hammer, a ton of iron; and we drop it on the pile-head with a velocity lower than a boy can give to a stone. Yet the pile moves; whereas under the tack-hammer it would not. Similarly, when we throw against the piston and cylinder walls the four fold more massive molecules of steam heat, even though moving with less than half the velocity of the flame molecules, the piston responds with a steadiness of real power which the gas engine piston knows nothing about.

118 The importance of the choice of proper mass for the performance of mechanical work is unquestionable. One of the first lessons learned by the boy in the shop is the selection of a proper weight of hammer for each job. All through the problems of engine designing mass is a prime factor. Yet mass is of no more importance in mechanics than is entropy in thermodynamics. It is as impossible to proceed intelligently in the solution of thermodynamic problems, without a finger-end concept of entropy, as it is to do good work in mechanics uninformed as to the reality of mass.

119 Anyone who has ever watched the prow of a massive ship forge slowly through the crib work of a wharf with which it was in collision, most deliberately yet almost irresistibly, will never say that there is no such thing in mechanics as mass. Yet the thing has been publicly and repeatedly said. It is similarly difficult to understand how anyone who has studiously watched steam at work, its entropy doing thermodynamically just what mass does in mechanics,

can ever say that entropy has no physical reality, or that it is of secondary interest to temperature in the study of thermodynamics.

120 In the engine recently referred to, the low pressure cylinder, which was over three times the volume of the high pressure cylinder, developed, when thus properly supplied with entropy, more power than the high pressure cylinder. Its proportion of power was as readily adjustable, by controlling the receiver pressure by means of the low-pressure cut off, as is the case in any compound steam engine.

121 The form of engine which was developed to carry on this cycle is worthy of brief mention. The problem of its design was stated in advance as follows:

a To provide for compound compression and expansion within a single machine;

b To transmit power directly from expander piston to compressor piston;

c To connect all pistons to a single crank and maintain proper constancy of crank effort;

d To follow standard steam engine construction, so far as possible.

122 While it has since been discovered that this statement of the problem was too rigid in some particulars, yet such it was supposed to be at the time that it confronted us. In its solution the third item of specification proved to be the most troublesome. Any possible arrangement of compressor and expander cylinders in tandem promised to give an abnormally vigorous impulse to the crank early in the stroke, followed by a vigorous negative pull on the crank shortly after mid-stroke. This phenomenon is a familiar one in all steam driven air compressors; but there, the air compression being the only duty, marked variations in speed are not objectionable. With us, however, compression was a merely incidental duty. The main task, the development of outside power, demanded an even speed and a constant crank effort.

123 The problem was finally solved by the arrangement of parts shown diagrammatically in Fig. 13. Therein HM is the high pressure motor cylinder, LM is the low pressure motor cylinder and C is the compressors, driven from a single cross-head. The underlying ideas were:

a To set the low pressure motor, which should normally develop one half the gross power, to driving the compressors, which, with their friction, might be expected to absorb almost one-half the same;

b To reserve the high pressure motor for driving the main shaft, quite as in an ordinary simple steam engine;

c To have the compressors so timed, with dead centers occurring ahead of those for the high pressure motor, that the former would develop their heavy resistance while the latter were still young and vigorous in their stroke;

d To develop the inertia forces needed to equalize the varying fluid pressures by heavy reciprocating rather than by heavy rotating masses.

124 All of this was accomplished by the use of a heavy triangular cast steel connecting rod for connecting the high and low motor pistons with the crank, and by setting the compressors tandem to the latter. This connecting rod served as a clearing house for all surplus or deficit of forces arising in either the upper or lower department. Late in the outward stroke the deficit below and the surplus above

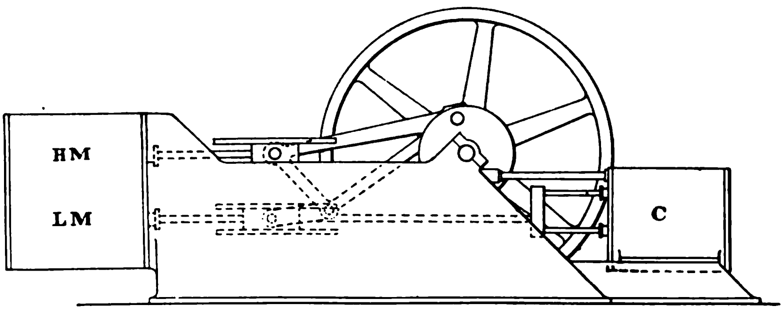

FIG. 13 ACTUAL CONSTRUCTIVE ARRANGEMENT OF ENGINE OF FIG. 9

combined in the triangle to develop a downward pressure on the crank pin. Late in the inward stroke they developed a similar upward force. The crank pin thus not only escaped all negative pull during its horizontal motion, but it experienced positive propulsion across dead centers as well.

125 Finally, the engine was equipped with double acting cylinders all around, with piston valves to the motor cylinders and with a Rites shaft governor for their control. The motor indicator cards were those of a standard compound shaft governor steam engine. The regulation was, of course, that of the automatic steam engine. Any other steam engine valve gear, including reversing gear, could have been used as well as that which was used. The motor cylinders measured 7 by 18 inches and 12 by 19 inches respectively; cylinder ratio, 3.22.

126 The exhaust from this engine looked exactly like that from a

steam engine. In fact, however, it was quite different. Its temperature, instead of being the 212 degrees fahr. which was called for by the barometric pressure, had it been pure steam, was well down toward the temperatures common in the exhaust pipes of condensing steam engines. Had the conditions of operation been more perfectly under control than is commonly the case with experimental engines, it might have been sent there.

127 Now it is a fact familiar to all versed in thermodynamics that the vacuum exhaust of a condensing steam engine is undertaken, not for the sake of the lowered back pressure, as was originally supposed, but for the sake of the lowered exhaust temperature; which, in the special case where steam is the working substance, cannot be procured without lowering the pressure below atmospheric, by means of the air pump and condenser. But this is a troublesome and costly process which is tolerated solely because it permits the exhaust temperature to be dropped from 212 to 125 degrees. It is the temperature range within the engine which measures its efficiency, not its pressure-range. On the other hand, it is the entropy range within the engine which measures its capacity, or power; and it is because the steam engine, with its restricted temperature range and much derided efficiency, possesses an enormous entropy range that it was the first to come into use, that it stands today the superior of the gas engine and that it will stay with us to the last.

128 Now in the engine just described there exists this combination of features, namely:

a An engine using liquid or gaseous fuel (that is, dispensing with the coal pile, pressure-boiler and grate),

b Developing its heat by a form of combustion, viz: a flame burning continuously under high pressure, which it is difficult to make imperfect and which is always more perfect than in the explosive type of engine, and

c From that white-hot combustion developing the sturdy entropy of steam heat, yet without the burdensome presence of a steam boiler under pressure or of the transmission of heat through metals,

d Expanding that steam heat from the highest practicable temperature of superheated steam down to

e The lowest temperature of exhaust which is useful with steam, yet without the burden of a condenser, air pump or a vacuum.

f In standard steam engine cylinders capable of all the double action, delicate regulation, margin of power, reversibility, etc., which are the standard attributes of the steam engine, and

g Involving the two additional advantages of

a the temporary absorption of negative work upon demand, and

b the transmission and subdivision of power from a central source.

129 The last item of all is the only one which has not yet been discussed, and it is the most important of them all from practical engineering considerations.

130 Immediately the imagination enters upon the field which such a prime mover might occupy in modern industrial enterprises it becomes evident that it will not be practicable, or convenient and profitable, at any rate, to equip each motor cylinder of a large system, which might include engines and services of the most diverse character, with its own set of compressors. But this is not necessary.

131 Let us imagine a central compressing plant, consisting of machines similar to the diagram of Fig. 12 but having compressors so large in proportion to the motors that there would be no surplus mechanical power after driving the compressors. Of the discharge from these compressors their own motors would absorb a minor fraction. The remainder would be available for distribution to distant combustion chambers feeding independent motors. These latter would be compound non-condensing engines of standard steam engine patterns, coming from the present builders of steam engines. They would be special only in that they would be fit for a throttle pressure of 300 or 400 pounds per square inch; their cylinders would be smaller than usual in proportion to their power and their weight of connections, etc. They would be cheaper per horse power than a standard compound condensing steam engine fit for the usual boiler pressure. They could easily be made of the most diverse types. Slow speed, high speed or reversing engines; turbines, steam hammers, pumps, etc., would all work on the same supply-system as they now do from a common boiler-plant.

132 Such a system would seem to be ideal in its elasticity of adaptation, in its freedom from all the costs and objections to the operation of a boiler plant and in its extension of the efficiency of the gas engine over the practicability of the steam engine. The wonder is, at first glance, why it has not long ago become a standard system of power development and distribution. Indeed, I believe that ultimately it will become, in essential, one of the most approved standard methods. But it has not yet done so; and it probably never will, in

just the form described. It is proper, therefore, to inquire wherein lie the unusual costs and obstacles which so beset and partially counterbalance such an attractive array of marked advantages.

133 These have already been partially stated. Most of them are involved in the greater volume of piston displacement demanded, and the incidental friction and first cost. These unusual costs will no doubt be justified, at times, by special advantages to be gained. But if the system is to be available for wide adoption they must be minimized.

134 The most obvious step to this end is the use of the turbine for the lower stages of pressure. The turbine has already signalized itself as a machine peculiarly adapted to the expansion of larger volumes at lower pressures than the piston can handle profitably. A few steam plants, particularly in France, have already carried this idea to its logical conclusion by using the piston and cylinder for the high pressure stage of expansion and the turbine for the low pressure stage; but only, the writer believes, where some special demand, such as reversibility in the upper stage, for rolling mill drives, gave emphasis to the advantages to be gained. In the central plant of an internal combustion power distributing system, such as was described, the special demand exists; and a turbine would there be used, without doubt, for the low-pressure stage of expansion.[1]

135 As to compression, however, there is less experience and more doubt, though the doubt is not a prohibitive one. Turbines have been connected directly to centrifugal fans and have developed a discharge pressure as high as five atmospheres with efficiencies ranging as high as 70 per cent; with the handling, of course, of volumes of air which are enormous in comparison with ordinary compressor capacities. Worked to even a much lower pressure than this, such a machine would so reduce the requisite piston displacement of a given plant as to bring costs and frictional losses within reason for any plant large enough to make the duplex character of the plant not undesirable in itself. The combination of high pressure reciprocating engines with low pressure turbines, which now promises to become standard practice, would be an ideal aid toward the practicability of this general plan.

136 There is another objection to the plan, however, which is more fundamental in character. This lies in the question of getting

[1] These pages were written not only before the recent decision of a British steamship company to equip one of its new steamers with a combination of high pressure reciprocating and low pressure turbine engines, but before the same plan was forecast for stationary power-plants by Mr. Henry Stott, of New York.

a cold plant into motion under load. When once in operation and hot, the margin of power, as already stated, is the equal or better of the steam engine. But for starting cold the system's reservoirs are of no avail, in comparison with the steam boiler. Nor can they compare even with the reliance of the ordinary gas engine upon a reservoir of compressed air for a start. In the explosive engine, one or two revolutions is usually enough to permit the engine to pick up its normal, or almost normal, supply of energy from the fuel. But in the constant pressure engine this is by no means so. The motive power is based upon the accumulation of a considerable store of temperature in the combustion-chamber and its accessories. Such a device will warm up more quickly than will a boiler and superheater; but the period during which combustion is maintained therein before substantial power is available is quite beyond the reach of any ordinary compressed-air reservoir.

137 In large plants a large reservoir might be used to warm up and start a little combustion chamber and engine, and that in turn used to "excite" the main engine; and where feasible at all such a plan would be entirely practicable. But it would still be a troublesome means of starting, and for the great majority of smaller plants it would be prohibitive.

138 What is wanted, then, is a self starting central plant, which shall pick up pressures in the system from atmospheric when everything is cold and do it quickly and easily.

139 Whereas the explosive cycle has been shown to be of an uncontrollable nature and unfit for the finer services which steam handles with perfect docility, yet the compression of air and gas is not one of those refined services. It needs to be performed efficiently; but it makes no demand at all for delicacy of speed regulation, nor for a wide margin of power at the motor end of the machine. Theoretically the power needed per stroke for a constant discharge pressure is constant. Actually only such variation is called for as will suffice to speed up or slow down to meet the varying volumes demanded, which is a question of machine friction only. For such a service, then, the explosive cycle, barring its demand for unusual fly wheels, is perfectly fitted. For the present, too, the present discrepancy in natural speed between gas engines and compressors will be overlooked; for a few high speed compressors have already been built with success, and more will follow so soon as a demand for them is felt.

140 In this connection some readers may recall with interest the struggles of years gone by for direct connection between steam engines and dynamos. Those who called for it were told by those who opposed

it that the two machines had natural speeds which were too far apart ever to be brought together. Yet now who ever sees a dynamo running at one speed driven by an engine running at another?

141 If we imagine, then, the central plant to consist of compressors direct driven from explosive engines, have we not the complete solution of the entire problem? The compressors, when the mains were empty, would offer no resistance but machine friction to starting; which is just the condition of affairs which makes the explosive engine easily self starting. This engine once started, pressures could be accumulated and the combustion chambers warmed up as deliberately, or almost as rapidly, as one pleased.

142 The picture becomes even more mechanical, natural and attractive if the type of explosion engine chosen for this work be the variable cut off, outside compression type, which was indicated in Fig. 8. That type was then described as preëminently adapted to compression. Moreover it will appear, if the actual design of such a central engine be undertaken, that it is urgently desirable that the expansion part of its process be divided into two stages, or compounded. For this the water filled cooling chamber, for exchanging temperature for entropy, stands ready, making the process feasible where otherwise it would be hopeless, or most difficult at least.

Mr. H. H. Suplee This discussion upon the division of the operation of the gas engine as regards the compression and the combustion leads me to call attention to the progress which has been made in the development of the Diesel motor in the United States. The principal difficulty with the Diesel motor, employing high air pressures, has been with the air compression pump. The air is partially compressed by a pump, directly connected to the engine, and the air delivered to the cylinder, where the final compression is effected. The American builders of the Diesel engine have modified this in a very practical manner by using an independent, two-stage compressor of a standard commercial type, driven by the motor, and delivering the compressed air to the engine or engines as the case may be. In this way the difficulties encountered with the compressing pump attached to the engine are eliminated, and the advantages of the latest type of separate compressor are realized. This is somewhat analogous to the present marine practice of employing independent air pumps, rather than pumps directly connected to the engine.

The Author The question of compounding touches the keynote of the gas engine problem of today. The gas engine discussion which

I have heard in the corridors since arriving at the meeting, has always turned upon one basic point, viz; Can the gas engine return enough in fuel saving to pay for the heavy investment involved? The same point has arisen several times in the auditorium discussion. The papers on foundry practice raise the corollary question: How can we procure castings of the weight (thickness) demanded by modern large power gas engines, and have them reliable?

2 All of this doubt regarding the gas engine rests upon one point, which was briefly mentioned in my paper but which needs emphasis, viz; That steam engine practice long ago taught us the commercial mistake involved in *trying to handle heavy pressures and large volumes on the same piston.* The remedy, in steam engineering, is compounding, or the use of a small piston to handle heavy pressures and of a separate larger piston to handle large volumes. I repeat that this is the prime reason for compounding. If an attempt were made to design a steam-engine to expand from a boiler pressure of 150 or 200 pounds down to an ordinary vacuum in simple cylinders, developing even as little as a few hundred horse power, such questions as maximum cross-head stress, regularity of crank-effort, effect of clearance, and valve-gear for extremely short cut-off would assume such importance that thermodynamic questions would quickly take secondary place. When the power developed runs into the thousands of horse power, as in marine practice, compounding becomes an absolute necessity from purely mechanical and commercial reasons. To throw modern boiler pressure upon a piston big enough to expand below atmospheric would demand cylinder-castings as massive as those smooth bore cast-iron cannon which now pass under the name of gas engine.

3 The gas engine, therefore, *must* seek similar relief in compounding. Yet we have never had even an attempt at true compounding in gas engine practice. The attachment of a further expansion cylinder, while the combustion cylinder still experiences atmospheric pressure on one stroke and explosive pressure on the next — still does the boy's job of displacing exhaust gases and metering fresh charge, while built for the man's job of handling the shock of explosion– is not compounding at all. In true compounding the high pressure cylinder does nothing but handle high pressures, and is small and strong without being ponderous. It carries receiver pressure as a back pressure, and never experiences atmospheric pressure. The low pressure cylinder coöperates by its contrast to this, in the handling of large volumes while protected from heavy pressures by the high-pressure cylinder; and so also avoids ponderousness.

4 To such compounding the gas engine *must* come. To its attainment the type described in the paper in Par. 68 et seq., combined with the processes of Fig. 11 and 12 in place of a receiver, offers facile approach. An engine designed along such lines would comprise:

a A compressing cylinder, big enough to handle the requisite quantity of fuel and strong enough to perform compression only:

b An explosion cylinder, strong enough to withstand explosive shock but *only big enough to stand the exploded charge half way to exhaust*, after which it exhausts under receiver back pressure, like any steam engine high pressure cylinder;

c A low pressure expansion cylinder, drawing from this receiver and expanding to atmospheric pressure, quite like any steam engine low pressure cylinder.

5 Such an engine could parallel the compound steam engine in cost per horse power, in large powers, and alone promises relief from the present limitation in the use of gas engines due to heavy first cost.

6 When it is added that, with outside compression, the limitation of degree of compression by preignition disappears from such a machine, it is obvious that improvement in thermodynamic efficiency may follow, if it does not lead, progress in commercial efficiency—as has always been the case in the history of steam engine compounding. In such a gas engine compression-pressures might be raised, as demand is felt, until the compression department operates in two, or even three or more, stages; yet no danger of preignition could arise. The obstacles to the indefinite increase of thermodynamic efficiency by increase of compression would then have become solely mechanical or commercial, rather than chemical or combustive, in their form.

No. 1169

THE FOUNDRY DEPARTMENT AND THE DEPARTMENT OF ENGINEERING DESIGN

By WILLIAM A. BOLE, PITTSBURG, PA.
Member of the Society

These notes have special reference to the design and manufacture of large and complicated castings; castings in which the material must be intrinsically strong and in which all of the various elements of a complicated casting must work harmoniously to accomplish the engineering purpose intended.

2 Small castings, as a rule, require much less consideration for two reasons: First; It is not usual to demand high strength in small iron castings because the designer will usually make a section thick enough to permit of pouring the metal—obtaining this information either from his own observation or by the foundryman's advice—and for most small objects the sections thus determined are more than ample for considerations of strength. Second; Thin castings, by virtue of their more rapid cooling, are almost certain to be stronger per unit section than would be the case if the same metal were poured into larger and heavier shapes.

3 Many large iron castings are, I believe, of questionable strength and of doubtful reliability, even though they have not as yet broken in service, because of internal strains and lack of harmony between their constructive elements. This may be true even though the casting is poured out of iron of the best quality, and may be due to inconsistencies of design occasioned by lack of experience on the part of the designer especially in the cooling and shrinking of the various parts of a large casting after being poured.

4 The physics of cooling, shrinking and synchronous contraction is a study which the foundryman should be better able to follow, and to become expert in, than the designer; and the engineering depart-

Presented at the New York Meeting (December 1907) of the American Society of Mechanical Engineers, and forming part of Volume 29 of the Transactions.

ment of a manufacturing plant making large iron castings of complicated shapes, would do well to consult foundry conditions very carefully before finally determining upon and accepting designs for such castings.

5 The foundryman's knowledge of the physics of the foundry should qualify him to anticipate some things not generally known to the average draftsman, and often not known to the supervising engineer.

6 The usual drawing room method is one of making assumptions in design by which sections of castings are regarded as beams of various sorts, loaded in various ways, as pillars, as sections in tension and sections in compression, etc. These assumptions are made as though the said members and said sections were of cold materials, put together in such a manner as to allow each section to remain normal to itself, as would be the case in building up a bridge truss, securing member to member by rivets or pins. Unfortunately for such assumptions the casting must go through the stages of molten, red hot and cold conditions before it is in its final form, and what happens during these changes of state may entirely upset the engineering assumptions upon which its members were calculated, and when the casting is cold, some members which were expected to be in tension may be in compression, and *vice versa;* others that had been intended for compression may be actually in tension. It is therefore necessary in designing to consider carefully whether the casting, after having passed through these formative stages, will ultimately be as the designer assumes.

7 Castings are often designed with a useless multiplicity of ribs, walls, gussets, brackets, etc., which by their asynchronous cooling and their inharmonious shrinkage and contraction, may entirely defeat the intention of the designer. He may find some of his walls, ribs, or brackets cracked before the casting is cleaned. It is sometimes possible to remove such superfluous walls, ribs and brackets, and thereby obtain not only a lighter but a stronger and more dependable casting.

8 It is highly essential that the designer keep in mind, as nearly as he can imagine, the cooling processes through which the casting must pass, and the effect which will be produced upon any given wall or member of the casting if it is cooled faster or slower than the other parts of the same casting. It would be difficult to set down any considerable number of rules governing this matter, but it may be of advantage to call attention to the necessity for careful study of this and of related subjects.

9 The outer walls of a casting, that is to say those which are more nearly adjacent to the sides and radiating surfaces of the flask, are naturally the first parts of a casting to lose heat, to fall in temperature, to begin to contract and to decrease all their linear dimensions. The inner walls of the same casting, being more isolated from the outer and conducting surfaces of the flask, may remain hot for a much longer period than the outer portions; as a consequence the outer members of certain castings may cool and take on their ultimate dimensions while the inner members are still very hot. The latter will, of course, ultimately cool off by conduction, but they will also continue to contract until at normal temperature, and their freedom of contraction may be prevented by the already determined dimensions of the outer walls; as a result there is likely to be violent tension strains in the interior walls of such castings. Sometimes these strains are sufficient to cause rupture while the casting is still in the mold; sometimes the casting does not rupture until it is out in service, and even if it breaks in service the rupture may not be produced by stresses of engineering design, but may be due to the original asynchronous cooling of the various parts of the casting.

10 There are some castings which, by virtue of their shapes, can be specially treated by the foundryman, and artificial cooling of certain critical parts may be effected in order to compel such parts to cool more rapidly than they would naturally do, and the strength of the casting may by such means be beneficially affected. As for instance in the case of a flywheel with heavy rim but comparatively light arms and hub; it may be beneficial to remove the flask and expose the rim to the air so as to hasten its natural rate of cooling, while the arms and hub are still kept muffled up in the sand of the mold and their cooling retarded as much as possible. Or in the case of a flywheel with an ordinary weight of rim and arm but with a heavy hub; the hub may be exposed and compelled to cool more readily than it naturally would, while the arms and rim are kept muffled in sand, and the synchronous cooling above referred to is at least approximated to a greater extent than if all parts were allowed to cool naturally.

11 It is often thought that large fillets are fine features of design in work of this sort, but many times they are highly detrimental to good results. Where two walls meet and intersect, as in the shape of a *T*, if a large fillet is swept at the juncture, there will be a pool of liquid metal at this point which will remain liquid for a longer time than either wall because of its lessened facilities for quick cooling, and this pool of liquid metal is bound to act as a feeder, supplying metal

for other parts, lower in the mold, that may shrink sooner, the result being, in practically every case, a void, or "draw," at the juncture point, bad enough in any case, but made worse by the presence of the large fillet. Of course there may be trouble from such intersections where no fillets at all are used, but the fillets should be kept small with the idea of allowing both walls and juncture to remain as nearly uniform in thickness as possible, and to have as nearly as may be the same capability for simultaneous shrinkage and solidification.

12 Among other classes of difficult castings I would place jacketed cylinders in the list of castings requiring careful consideration in design. In considering the case of a gas engine cylinder which is to be jacketed, the inner wall which resists the strain of explosion must be quite thick in order to afford the requisite strength against explosion pressures of ordinary nature and also against abnormal pressures due to pre-ignition and other causes. A cylinder of this sort, whose internal diameter might be 40 inches, could well have a thickness of cylinder wall amounting to 3 inches or more. The outer wall forming the jacket has only to stand the ordinary pressure of the cooling water, which might be quite low, often not exceeding 60 to 80 pounds per square inch, even where water is used direct from the city mains, and an outer jacket wall 1 inch thick might, on ordinary engineering assumptions, be regarded as ample to care for this pressure.

13 If the cylinder wall and the jacket wall are continuous, that is to say, if each extends rigidly from one end of the cylinder to the other, there is likely to be trouble when such a cylinder is cast or cooled, and even if it does not break at the start it is quite likely to break in service later because of the fact that a wall of metal 1 inch thick located out near the sides of the flask which acts as a cooling medium, will not shrink in time with the inner wall whose thickness is three times as great and whose opportunity for radiation is quite inferior. It is reasonable to expect that the outer wall will cool first; will take on its final dimensions while the inner wall is still very hot; at a later period the inner wall will shrink to normal temperature and will find that its desire to contract is restricted by the compressive strength of the outer jacket wall, and the effect is a high degree of tension in the working cylinder wall. In such a case one good feature of design is to interrupt the jacket wall so that the inner or working wall may have its own way and be unhampered in contracting; afterward it is closed up and rendered water tight by suitable mechanical means.

14 In such a case as that just cited, if the jacket wall must be cast continuous with the cylinder wall, it should not be designed solely in

connection with its own theoretical stresses, but should be thickened up and made to approximate the working cylinder wall, so that it may cool down and contract more nearly simultaneously with the same, thus relieving the casting of stresses produced by asynchronous cooling. Such outer walls, and all such attachments to a large casting, as bosses, pads, and the like, should be designed not alone out of consideration to the working strains which will be applied to such bosses or pads, but the tendency of the iron to chill at such spots must be considered, and often the pads or the bosses require to be made several times as large as mere reasons of strength would dictate, to avoid a hardening and whitening of the iron in thin sections that would prevent its being machined to required dimensions.

15 After the foundryman has accepted the design and begun the work he may have several things to do in order to produce a reliable casting. If it is a cored casting he must guard against the cores being so strong that when confined within the contracting casting they will produce rupture of the metal. Among the usual means employed for producing a collapsible condition of core may be mentioned the use of saw-dust or coke or ashes, or a combination of them all, some of which ingredients will burn out as the casting cools and provide thereby for a collapse of the core. In other cases removable pieces, collapsible core arbors, straw wrapped core arbors and the like, tend to prevent castings from cracking because of an unyielding core.

16 In order to serve engineering purposes, castings should be not only apparently sound but really so. For this purpose risers and sink heads should often be employed on iron castings where they are not at present used. Steel foundry conditions compel such precautions to insure soundness, but in large iron foundry work interior cavities may exist without detection, and some of these may be avoided by the use of suitable feeding devices, risers and sink heads. If risers are not employed, the upper or cope side of the casting is likely not to be solid, because of the metal in the upper portions flowing or bleeding away from the interior of these sections to feed the shrinkage and the contraction in the lower portions of the casting. Gravitation is at work here as elsewhere, and as the sections of the casting that are lowest cool and pass from the liquid to the solid state, the diminished volume of the solidified iron produces demands for fresh liquid metal from above to fill the voids, so that the upper portion of the casting is in such cases sacrificed for the benefit of the lower part. The top surface of such a casting may apparently be solid, but if drilled deeply, as for stud bolts or other purposes, it is likely that cavities and extreme openness of grain will be disclosed.

In some such cases good can be accomplished by the use of local chills placed under the top flange, if a cylinder for instance which chills will *set* the metal in the flange before it has time to feed out of this region into any lower portion of the casting.

17 If specifications do not call for sink heads or risers, they may not be applied in the foundry, if the foundry has no interest in the design, and the resulting casting may be quite otherwise than as the engineering department had anticipated. The making and the cutting off of the sink head costs the foundryman heavily, and he may not be willing to spend the extra cost involved in the sink head method, and he may really not know whether the requirements are severe or otherwise.

18 In some large castings intrinsic strength per unit section may not be a serious requirement. The amount of metal provided for reasons of mass, or for other reasons, being so ample that the working strains per unit section are low and are easily complied with. In other cases the engineering design may require high quality of material because high working strains per unit section are to be imposed upon the finished casting. In such cases engineering attention should be paid to the size of the test specimen which is to furnish an index of quality, and to the relation which exists between the strength of cast iron when cast into light test pieces and that of the same metal when cast into heavy sections.

19 The writer has taken specimens from an iron casting having at one point in the casting tensile strength as high as 30 250 pounds per square inch, and as low as 20 502 per square inch in another and heavier section. The difference in this was wholly related to the thickness of the section and to the rate or speed of cooling, with its consequent effect upon the grain, and upon the strength of the iron of which the casting was composed. It might be said that large sections cannot be cast to yield the high strength that is sometimes associated in engineering minds with specimen test pieces cast in smaller sections of prevailing sizes.

20 It is well that the foundryman be acquainted to some extent with the engineering purposes for which these castings are intended. This knowledge will enable him to pay particular attention to such points or parts of the casting as are specially critical and to such as are to be machine finished. He can usually arrange to place his chaplets, anchors and core vents so as to keep them clear of the working or sliding machined surfaces, and he can then better provide for producing a casting which is a clean one at these critical points. The molder, if left to himself, may and probably will, put chaplets

and anchors directly in the path of a machined slide, unless someone who knows better sees him and prevents it. Sometimes this kind of information would seem to be obvious, but often it is not so, and a hollow cylindrical casting with flanges on each end, might, for all the molder knows, be a pipe having no special requirements, whereas it was intended to be a cylinder, which must be bored, faced and generally machined, and must be perfectly free from defects, and a casting in which chaplets and anchors are utterly inadmissible.

21 Certain points or spots on a large casting may require to be drilled and tapped and may demand a high quality at that spot. A suitably located chill will insure soundness and solidity here if the

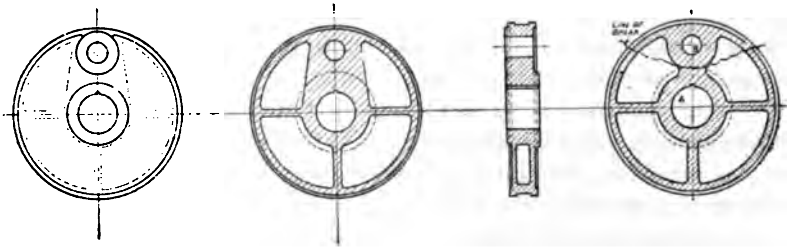

FIG. 1 CRANK ILLUSTRATION

foundryman knows what is demanded; if he does not know, the casting is made, looks good to him, is shipped out, and when machined is found to be hollow, cavitated or spongy at the critical spot.

22 In ordinary cases, designs for castings should be such that it will not be necessary for the foundryman to pay particular and extraordinary attention to special or heat treatment, because in the press of other matters, such treatment may occasionally be forgotten and omitted, or it may be imperfectly done by inexperienced men. A casting is best designed if it can be uncovered promptly after pouring, lifted out of its bed and deposited on the floor of the chipping shop. This is what is done with 95 per cent of the output of the average foundry, and it is what the workmen are accustomed to. Special cases soon become irksome and someone will perhaps assume the responsibility of saying: "This special treatment is all foolishness and the casting is just as good without it." There are, however, cases in which it is necessary to design castings that do demand this special treatment.

23 Fig. 1 is a sketch of a peculiar crank disc which was made in an iron foundry under the author's management some five or six years ago.

24 The first casting was poured in the usual and ordinary manner, and after a decent delay in the flask was uncovered and removed to the chipping shop. It lay on the floor of the latter department for a day or two after cleaning; it was then shipped to the machine shop, which is located about twelve miles away. When the casting arrived at the machine shop it was found that it had been so stressed by internal strains that a large piece had not only broken away from the balance of the casting, but it had jumped clear off the railway car on which it was being conveyed, and the missing piece was found by a track walker alongside of the railway track a few hours after its loss was reported. The line of breakage is indicated on the sketch, and the missing piece weighed perhaps 1½ to 2 tons. This case was studied carefully; the heavier interior member, being the last of the casting to cool, had set up the violent internal strains which caused the casting to rupture.

25 We arranged the next casting so that a few minutes after pouring had been done, a small stream of water in a regulated quantity was caused to drop into the hollow cores *A* and *B*, as shown on the sketch, compelling the hubs surrounding these cores to cool in advance of their natural time, and at least approximate synchronous cooling with the balance of the casting. The other portions of the casting during this period were kept muffled up in the sand and their cooling was delayed, while the cooling of the crank hubs was accelerated. After this method was adopted, twelve such castings were made, all good, and they have been in service for some years.

COOLING TREATMENT FOR SPECIAL CASES

26 The writer had to produce a number of large cylinder heads for Corliss engines, these heads having ports for steam and exhaust valves formed in the heads. Structurally considered, these heads were like a cylindrical steam drum of large diameter but of very short length, having a flat head at each end, and were required to stand internal pressure.

27 Considering the resistance to internal pressure, the cylindrical shell or outer wall could be designed quite thin as the strains in it were all tensile strains, while the heads, being flat and of great area, were subject to bending strains which demanded that these be greatly thickened up to make the flat surfaces, not easily stayed or braced together, strong enough to carry safely the pressure. In addition to this greater thickness of flat head, allowance had to be made for a machine finish on the flat surface, which was not required

by the shell, and the disparity thus became still greater. The port openings for the admission and exhaust of steam made large holes in this head or flat plate, which were to be tied across ports by bars or ribs. In cooling by natural processes these bars almost invariably cracked in the casting, because the cylindrical shell being thin, cooled first, and was assisted in doing so by its position which was very close to the sides of the flask, where radiation was active. The flat head, on the contrary, was at the bottom of the flask, where radiation was poorer, and it was practically twice as thick as the rim, and cooled more than twice as slowly. With these divergent tendencies in the casting trouble ensued. The rim cooled early and took on its final dimensions and in the form of a circle opposed to compression—the strongest possible shape. The head, or plate, or diaphragm, cooling later, had its contraction tendency resisted by the stiff rim and a struggle was set up. The tension member was of course the weaker and the large openings in the latter made the result a foregone conclusion—the diaphragm simply had to shrink or be stretched, the rim would not give—the ribs broke.

28 We cured this trouble by the following means: In the drag portion of the mold we placed a spiral coil of iron pipe through which we could circulate cooling water. This coil was placed as close to the face of the pattern as was considered safe, about 1½ inches away. The inner cores by which the head was hollowed out were also provided with similar interior cooling coils and the cope had a coil like that of the drag. After the casting was poured we waited for a few minutes to enable solidification to begin, and then we turned water into these cooling coils, and connecting the overflow to sewer connection, let the water run all night. The casting lay in the mold, the rim kept muffled in sand to delay cooling, while the coils close to the heads accelerated cooling. The result was most satisfactory and the castings produced by this process have stood the severest tests of several years continuous duty without failure. Heads of similar design made by other foundries cracked systematically, sometimes while the casting was still in the foundry, sometimes in the machine shop, but quite frequently not until after the engines were put into operation. In all cases the stress was there and the only question was, *when* it would cause breakage. See Fig. 2.

SHAPES

29 It might seem almost unnecessary to say that shapes of sections, flanges and other projections, should be so designed that the molder may most easily produce the desired shape without having

to use complicated means. If the designer or draftsman were a man who had a little practical experience in foundry work he would see numerous opportunities for making shapes that would "draw" easily, rather than certain other shapes that look well on paper but

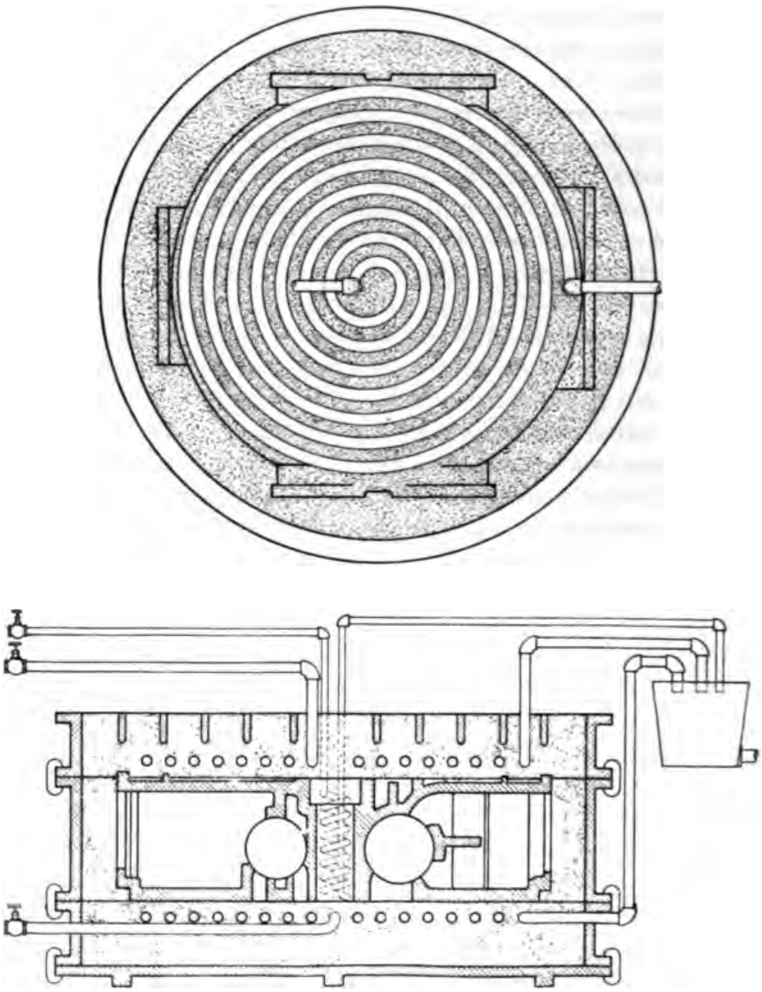

FIG. 2 CYLINDER HEAD

are much harder to produce. Of course the foundryman can produce almost any conceivable shape if he has to, but engineering design is at its best when its shapes are at once suitable for the intended purpose and easily and cheaply produced. On work of considerable size a little more time required to deal with a detail may prevent doing any pouring today, with a strong probability that the molder can make that job last him "until tomorrow night." The designer should try to put himself in the molder's place and imagine himself making the mold in question. Then he will see what a small difference in design sometimes causes a big difference in cost and risk. An instance of this is Fig. 3 and represents a prospective nozzle with a flange for steam or water connection.

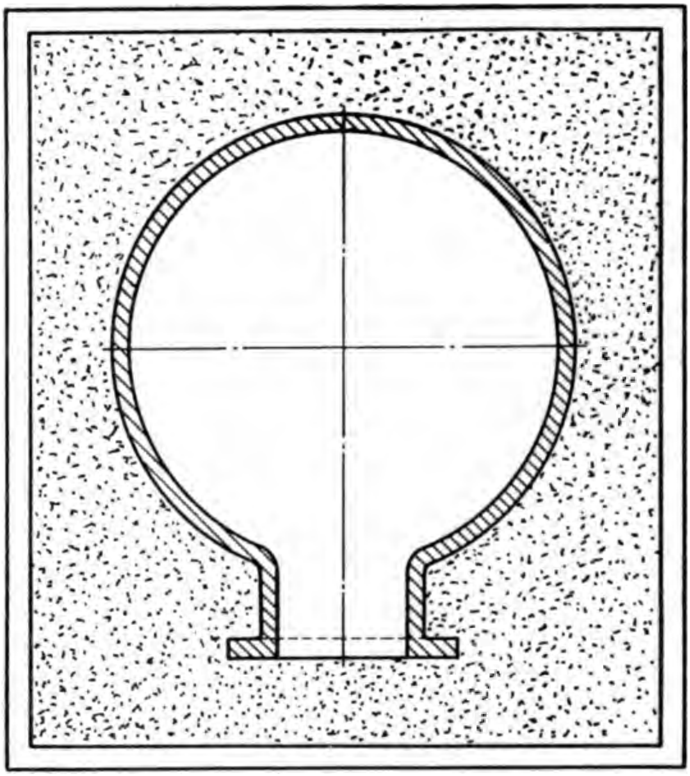

FIG. 3

30 If the flange in Fig. 3 is at the bottom of a complicated casting it will require the flange pattern to be cut into removable sections or a troublesome embedded core is required. If practicable to design as in Fig. 4, the neck draws naturally and the main core forms the flange. This sort of change may not always be possible, as certain designs will demand loose bolts, while Fig. 4 would call for stud bolts, but there are cases in which the foundry's troubles can be reduced in this manner.

31 It is not supposed that the foregoing is in any sense exhaustive, and it is presented with the idea chiefly of calling more attention than is usually given to the relation which exists between good design and good foundry practice, and to some of the physical phenomena connected with the manufacture of large and complicated shapes in iron castings.

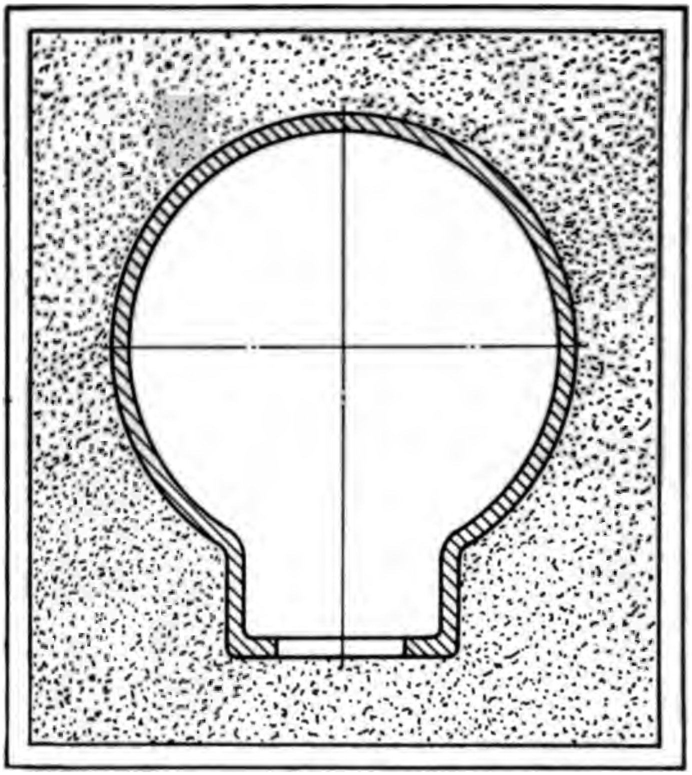

FIG. 4

32 Breakages are sometimes difficult to account for, and the designer may think the fault is with the quality of the iron which has nothing at all to do with the trouble, and when the shape and design are the true cause. The "physics of the foundry" were not properly understood when the design was made.

33 If this paper can have the effect of making the designers of cast iron structures very carefully consider the foundry's physical problems it will have accomplished the purpose of its author.

DISCUSSION

Mr. A. B. Carhart I want to ask the effect of increasing the size of the fillet from the flange to the main body portion upon the castings of iron valve-bodies weighing from 100 to 200 pounds. I find there is a difference of opinion between the foundrymen and the pattern designers as to the desirability of increasing and enlarging the fillet to leave a larger body of the metal at the point where the body gradually tapers off into the flange. The foundrymen claim, as in this paper, that too large a fillet is undesirable. Can anyone confirm our experience, that too great a body of metal in that part induces a porous condition which tends to weaken the structure?

Mr. Edward N. Trump My experience in the designing of many large castings, especially rings and bases of large apparatus, ten to thirteen feet in diameter, has convinced me that it is especially important to keep very even sections of metal; that wherever there is a body that is a little larger than the rest it does not cool quite so fast and from that part the metal is drawn to the other parts.

2 Recently in the case of a flange some ten feet in diameter, the designer wanted to get a little greater distance between the two heads on a ten foot cross, the heads being for tubes, and he thickened the metal up about one half inch at the flange and also put in quite a large fillet. That seemed to keep the flange from cooling. When the flange came to be drilled for holes around the outside edge, it was found that every hole had an opening in its center which communicated with the inside. The consequence was that they all had to be bushed in order to keep them tight. I know of the case of a flange where, although the outside skin showed no apparent rupture in any way, yet when it was broken open it was found to have holes of this character.

3 We have found in other cases where we put in an additional section on a small part which cooled more slowly than the rest that it was sure to give us trouble; we always had empty spaces caused by the shrinkage.

Mr. A. D. Williams In the ingot buggies used in steel mills, where the ingots are cast upon cars, it has been found that unless the section of metal was kept uniform the buggies often gave out under the stripper, the top of the buggy being pushed down on the axles. The result of experiences of this kind has been to modify the early designs, big fillets were cut out and the edges of the car are rounded over to form the sides, the thickness being kept uniform throughout.

2 We used to employ a great many gear wheels, and had a great deal of trouble from shrinkage over the arms where they joined the rim. These defects were expensive, as they were rarely discovered until the wheel had been partially finished. The difficulty was overcome by putting a gate or sinking head on the rim at each arm. After this was done there was comparatively little trouble. The foundrymen who did the work for us tried a great many experiments and different mixtures of iron before they discovered the simple remedy for the trouble.

MR. H. M. LANE Where a fillet is necessary trouble can often be avoided by putting a chill on the casting at that point, so as to chill the larger body of metal at the same time that the rest of the casting is cooling. The writer knows of several cases in which it has been done successfully in air compressor work.

2 In reply to Mr. Williams' remark about putting in a riser, if bronze work is being dealt with, a shrink boss will correct the difficulty.

3 There is a very marked difference between cast iron and most of the alloys. The alloys set in a mold with a flexible skin, and that skin bends or yields as shrinkage takes place. The writer split some shrink bosses recently to see if there were any blowholes, cavities or pockets inside. None whatever were found, but the bosses showed great deformation on the outside. This will occur in bronze and in a great many of the copper alloys, but in cast iron or steel, the skin is not flexible to the same extent, although it is more so in steel than in cast iron. It sets at once and takes its permanent form; then the shrinkage is not toward the core, but toward the skin, and instead of the hollow occurring on the outside, as in bronze castings, it occurs on the inside as a shrink hole. Any substance, as gas, expanding on the inside, causes a blowhole and will necessarily have a smooth surface; but if the hole is caused by shrinkage it will have an angular rough surface. There is no doubt about what causes these holes. If the hole is caused by dirt being in the casting, the dirt is there when the casting is broken open.

4 A flywheel explosion, a few years ago, wrecked an entire building, and the writer took pains to obtain the piece of the wheel which had caused the most damage. The wheel was provided with a very heavy fillet at the outer end of each arm, in which was a hole large enough to lay the hand in, indicating a tremendous shrinkage in the casting at that point. It was a band flywheel, and the rim of the

wheel in the center was about four inches in thickness and about 2½ inches at the outside, and with nearly a 40-inch face. It had quite a heavy rib around the center, but there was this enormous pocket where the heavy fillets joined. The arms were bolted on. Other flywheel manufacturers have had the same experience, and the flywheel design has been changed in a number of instances in order to omit the fillet.

5 Here is another case: In the anthracite coal region a great deal of trouble was found with the partition in the pumps between the dead ends; that is, the dead-end partition between the two plungers that work toward each other. That partition is sometimes 14 inches in diameter and it must withstand a pressure of possibly 800 pounds to the square inch, so that it requires a considerable thickness of metal. The matter of clearance is of no account. The partition was eaten right through by the mine water, so that in a short time the pump was chugging the water back and forth, and the question was raised as to why it was eaten through. The writer broke up some of the material and photographed the pieces. There were large pockets in them. By breaking a comparatively new casting, it was found that the heavy fillet and the extra thick metal had resulted in an open porous structure through which the acid water had eaten a passage of five or six square inches of area.

6 The difficulty was overcome in the following manner. The bore of the pump cylinder was about an inch and a quarter thick. A 14-inch partition was built up of one-inch metal, stiffened by two-inch ribs one inch thick. By dividing the strengthening metal and the partition into one-inch metal so that it cooled quickly, the heavy fillet was dispensed with and a casting was obtained which lasted four or five times as long.

7 A fillet may be altogether too thick, and in a great many cases it should be dispensed with almost entirely, the design of the flywheel being changed in such a way as to get as uniform metal as possible, and the strength secured by some other method.

Mr. J. E. Johnson, Jr. The size of a fillet is a matter that depends a great deal upon the amount of additional metal. It is a well known fact that a thick place in a casting will feed the surrounding parts of the casting. That is what causes shrinkages, or cavities. It makes a sponge of metal at these portions. The great majority of construction engineers do not realize its importance.

2 In confirmation of Mr. Lane's statement concerning shrinkage cavities, the writer once had made a pulley three feet in diameter,

having six arms and a very thin rim about two inches wide. It was flanged, and the flanges being low, the rim had been cast solid and the center turned out to leave a rim about one-half an inch high on each side, leaving the metal in the rim proper quite thin, as it was desired to be very light, and as a result one could see on the face of the pulley the outline of the cross-section of each arm in a porous spongy metal much darker in shade than the rest. It was not a serious weakness for the purpose for which the pulley was intended. It is still in service after several years use, but it was a clear indication of the effect which is practically always produced by a change in section, or the junction of two sections of a casting.

3 Just as much harm can be done by doing without fillets where they are needed as by putting them in where they are not needed.

4 Every one is probably familiar with the case that Whitworth illustrated, years ago, of a hydraulic cylinder about a foot in diameter inside and with six inches of thickness of metal. He made them with square bottoms, and the bottom simply shot out as a conical plug, running from the inside corner to the outside corner, because the crystallization from the cylindrical portion was at right angles to that portion, and the crystallization of the bottom portion was at right angles to that. Where these two lines of crystals met at a sharp angle they did not unite properly, and while the metal was not separated on that line it had very little strength, and the castings gave way under pressure. Then others were made exactly the same, but with the bottom hemispherical inside and out, making a continuous change in the direction of crystallization, with the result that the trouble was corrected completely.

THE AUTHOR Regarding the use of fillets, I do not object to the use of any except those which are too large. It would be equally as bad to omit a fillet where it is required as to make it excessively large and have the interior bleed away. A fillet of some size is necessary at practically every junction of two walls of a casting, and my judgment is that a small fillet is often far better than a big one.

No. 1170

MOLDING SAND

The Improvement of Molding Sand by Mechanical Treatment

By ALEXANDER E. OUTERBRIDGE, JR.,[1] PHILADELPHIA, PA.
Non-Member

It is no exaggeration to say that foundry practice, in this country at least, has been revolutionized within the past twenty-five years through the substitution of scientific for empirical methods.

2 The relation between the chemical composition and physical properties of metallic alloys used in founding — thanks to the pioneer investigations of Professor Turner and others — is now very generally known, and practical application is made of this knowledge in all modern plants.

3 Next in importance to the various metals of which castings are made, if not indeed of equal importance therewith, must be classed the material of which the molds and cores are composed. Strange to say, there is comparatively little literature dealing with this important topic in a scientific way and little is found in technical magazines and in the Transactions of the Engineering Societies. It remains for some one to collate the facts and to present them in a form available to the founder.

4 The writer having been invited to contribute a paper to a symposium upon the subject of molding sand and its treatment will confine his remarks to the practical side of the question and endeavor to show how greatly molding sand, including core sand, can be improved in its physical properties by correct mechanical treatment; and at the same time, how the cost of preparation of the sand for molds and cores can be greatly reduced as compared with the old fashioned methods that are still in vogue in many establishments.

Presented at the New York Meeting (December 1907) of The American Society of Mechanical Engineers, and forming part of Volume 29 of the Transactions.

[1]Engineer with Wm. Sellers & Co., Inc., Philadelphia, Pa.

5 In the effort to prevent costly "wasters" in the foundry, which sometimes wipe out the estimated profit on some specific jobs, the composition and physical properties of the different varieties of molding sand used in the foundry of William Sellers & Co. Incorporated, first became the subject of careful study by the writer more than fifteen years ago.

6 The selection of sand suitable for all purposes in the foundry constituted at that time a not unimportant part of the duty of the very competent foundry foreman.

7 It was found on looking into the matter that the only tests — if tests they could be called — which were then made of new sand were two in number and exceedingly crude in kind, one being for "toughness," a most important, indeed essential property, the other for "porosity."

8 The expert's test for toughness consisted simply in squeezing a handful of the sand into the form of a ball and then breaking it, little or no attention being paid, by the way, to the degree of dampness or the more or less heterogeneous composition of the sand. The porosity test consisted, in like manner, in compressing gently a small quantity of the sand between the palms of the hands and then blowing through it. While such tests may seem absolutely absurd in their crudity it must be admitted that in the hands of an expert they afford a fair degree of practical knowledge of the average quality of the molding sand.

9 In order to improve, if possible, on these time honored methods of testing sand, the first plan devised was to make a number of test bars of "green" sand, 6 by 1 by 1 inches, under uniform conditions of pressure, dampness, and quantity of material used in forming the molds. These little test bars were placed upon a smooth metal plate with sharp and square edges. The bars were then pushed over the edge of the plate, until they broke, when the amount of the "overhang" was measured. It was soon found that there was a great difference in the length of the overhang, which was regarded as a quantitative measure of toughness of the sand; these differences were not even noticeable by the crude ball test.

10 Samples taken from different parts of a small heap of sand that had been uniformly dampened or "tempered," varied greatly in this respect, owing, no doubt, to the irregular distribution of the alumina or clay binder, and the correctness of this inference was subsequently confirmed by simple analytical tests.

11 After a sufficient number of these test bars had been made and broken to prove the reliability of the method, further tests were

devised to ascertain whether the usual methods of riddling and mixing sand for the molder's use affected its quality either by increasing or decreasing its toughness, as shown by the amount of overhang of similar test bars of green sand. It was proved that the more thoroughly the sand was worked the greater the overhang, due as already stated, to the more uniform distribution of the binder.

12 The ideal molding sand is a material in which the individual grains of silex, constituting approximately 90 per cent of the mass, are completely covered with an overcoat of alumina or clay, and the more uniform the grains are in size and shape the better is the sand with respect to porosity in relation to the average size of the grains.

13 It was found on passing a sample of sand a number of times through a hand riddle and making test bars from the sample after each riddling that the overhang was increased measurably. Thus, a sample of sand which, after tempering and mixing by hand with a spade, showed an overhang of less than two inches of the test bar, increased to nearly three inches after a dozen riddlings.

14 It would not be practicable to treat large masses of sand in this manner, even though a positive and valuable gain in the quality of the sand should be demonstrated by making test molds from patterns having considerable overhang in places, or in making fine toothed gear wheels, etc.; nevertheless the information thus obtained was quite valuable and led to important practical results, as will be seen presently.

15 Another novel observation was concurrently made, *viz.* that the increase in toughness and porosity noticed in these tests might be partly due to "aëration", or to the separation of the grains of sand when falling from the sieve to the floor. In order to discover the truth or falsity of this view, a quantity of the sand was shaken in a box with a closed lid for several minutes, and test bars were made before and after shaking, the correctness of this theory was quickly shown, for the shaking without sieving proved to be more effective than the sieving without shaking.

16 Tests for porosity alone were also made, but as these were not very satisfactory, owing possibly to want of suitable means of accurately controlling and measuring the amount of air drawn through a mass of sand compressed in a tube, these tests were not prosecuted to a conclusion.

17 About this time William Sellers & Co., Inc., began to experiment with a centrifugal machine for mixing sand, and it was found that the desired result could be obtained with such a machine much more expeditiously and economically than by any treatment with

riddles or chasers in a rolling mill, and at the same time, the toughness and the porosity were increased to a very much greater degree than was possible by the old methods. These satisfactory results led to further experiments in this direction that culminated in the development of a thoroughly practical centrifugal machine, simple in design and substantial in character, which proved so valuable in the foundry that it was placed on the market, and a large number are now in regular use in some of the largest establishments in the country as well as in many smaller foundries.

18 The machine accomplishes as much work in one hour by the help of two laborers, in preparing molding sand, as five men could do in ten hours by the old method. Before proceeding to describe the machine itself, attention is called to the half tone illustrations Fig. 1 and 2 showing tests made with facing sand for large and medium work before and after treatment by this new process.

19 There are three grades of molding sand in addition to core sand regularly prepared and used in the foundry for the different classes of work. They are classified under the names "Strong Sand," "Special Strong Sand" and "Fine Sand."

20 The Strong Sand is used for the majority of the large molds, such as planer beds and uprights, etc., and for the principal parts of other large machine tools. Most of these molds are skin dried, or baked on the surface, *in situ* by means of a portable drying oven after having been "wet-blacked".

21 The Special Strong Sand is used only for molds for the heaviest castings, such as large anvil blocks, etc., these molds are also wet-blacked and when baked on the floor are almost as hard as a stone or as hard as a baked loam mold; this mixture is all new sand.

22 The Fine Sand is used for all light castings and much of the "medium" work; these molds are not baked and constitute what are commonly called "Green Sand Molds".

23 It may be interesting to know the formulae for the preparation of the three grades of molding sand given below:

STRONG SAND

Strong Lumberton sand .... (new)	= 14 parts
Gravel .... (new)	= 7 parts
Floor sand .... (old)	= 6 parts
Coal dust	= 2 parts

SPECIAL STRONG SAND

Strong Lumberton sand .... (new)	= 9 parts
Gravel .... (new)	= 14 parts
Coal dust .... (new)	= 2 parts

FINE SAND

Weak Lumberton sand	(new)	= 14 parts
Fine floor sand	(old)	= 4 parts
Coal dust		= 2 parts

24 Fig. 1 is from a photograph showing eleven bars, (6 by 1 by 1 inches) made from Strong Sand under uniform conditions of quantity, temper (dampness) and pressure of sand. The bar labeled *0* was pressed from a sample of the sand after having been dampened and turned over several times with a spade and only partially mixed; the object of such preliminary mixing is simply to prevent the coal dust from flying out of the centrifugal machine on subsequent treatment. The other bars were made from the same pile of Strong Sand

FIG. 1 GREEN SAND TEST BARS MADE FROM ONE SAMPLE OF SAND

after passing through the centrifugal sand mixing machine from one to ten times. These bars were all laid side by side upon the smooth metal plate (about ¼ inch thick) resting upon a table, and they were slowly pushed over the edge of the plate until they broke.

25 The following table gives the measurements of the overhang of each bar as nearly as the somewhat irregular shape of the break permitted.

No. 0 Length of overhang = 2¼ inches
No. 1 Length of overhang = 3 inches
No. 2 Length of overhang = 3¼ inches
No. 3 Length of overhang = 3⅜ inches
No. 4 Length of overhang = 3½ inches
No. 5 Length of overhang = 3½ inches
No. 6 Length of overhang = 3½ inches
No. 7 Length of overhang = 3⅝ inches

No. 8 Length of overhang = $3\frac{3}{4}$ inches
No. 9 Length of overhang = $3\frac{3}{4}$ inches
No. 10 Length of overhang = $3\frac{3}{4}$ inches

26 It will be observed that the first treatment increased the overhang three quarters of an inch, the subsequent treatments increased the overhang in some cases one quarter of an inch, and in some cases not measurably. The first treatment was therefore the most effective, and for practical purposes, one treatment is often sufficient to insure good mixing of the materials and thorough disintegration of any lumps.

27 It may be stated *en passant* that the machine is not designed to remove nails, jaggers, or stones. If the sand contains such things it should be put once through a very coarse screen to remove them before passing into the centrifugal machine.

28 The strain tending to break the sand beam is increased by the additional weight of the increasing length of the overhanging portion and also by the increased moment of its center of gravity; it is readily seen, therefore, that an increase in length of the overhang of three quarters of an inch on the first treatment in the centrifugal machine means an increased tenacity of 75 per cent; in like manner an increase in overhang of 50 per cent means an increase in strength of sand of 225 per cent.

29 The illustration Fig. 2 shows the fractured surfaces of the same bars.

30 Bar No. 0 shows the heterogeneous components of the partly mixed sand, while the other fractures show increasing uniformity due to more thorough mixing and disintegration of lumps of gravel, up to No. 3, after which no further increase in uniformity is observable to the eye.

31 The illustrations convey a very fair impression of the actual appearance of the bars. The appearance of the fractured surfaces coincides with the tests for overhang and shows that a single treatment in this machine is, in many cases, sufficient, and two treatments are all that are usually needed with any sand mixtures.

32 In mixing core sand containing flour, the effectiveness of this centrifugal method is still more strikingly evident owing to the almost total disappearance of the white flour due to its thorough commingling with the sand and black coal in one treatment.

33 The tests here shown are typical of many others of similar nature that have been made, but to give a detailed statement of these would extend this paper beyond the desired limits.

34 In recent years there has been a remarkable reduction effected in the cost, skill required, and time consumed in making cores by the use of sharp sand and oil in place of the usual core sand mixed with flour or other binders.

35 The oil sand cores require no ramming and are made by

FIG. 2 FRACTURED SURFACES OF GREEN SAND TEST BARS

unskilled labor; cases almost without number might be cited where the actual cost of cores has been reduced by the oil sand method from 50 to 75 per cent and over, and better results obtained in the foundry, with fewer wasters caused by the breaking down or "blowing" of cores; no venting and but few corerods are needed. Thorough mixing of the linseed oil with the sharp sand is absolutely necessary, though rather difficult to obtain and in accomplishing this the centrifugal machine is preëminent; in fact, it would be impossible without this machine to produce the remarkable results that are now daily recorded with oil sand cores in the foundry.

36 The centrifugal machine is, of course, equally well adapted to the thorough mixing of core sand with the various core oils and core compounds that are sold for making cores.

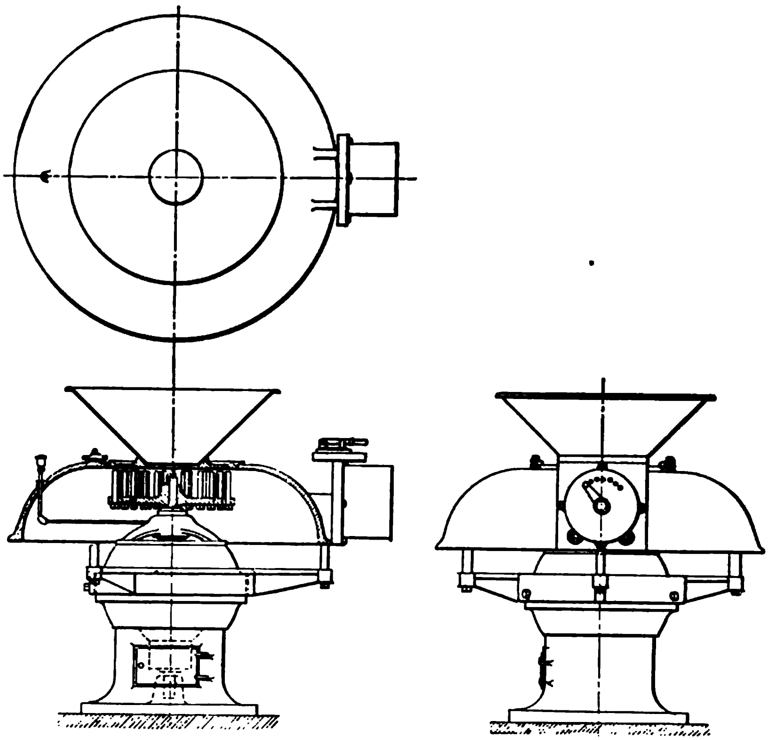

FIG. 3 SECTIONAL DRAWING OF CENTRIFUGAL SAND MIXING MACHINE MOTOR DRIVE

37 Experience has shown that in mixing sharp sand with oil for cores, the centrifugal machine should be run at a lower rate of speed than when mixing and at the same time tempering ordinary molding sand. Two treatments are sufficient to insure thorough mixing of sharp sand and oil for oil cores.

38 In conclusion, it will suffice to give a very brief description of the Centrifugal Sand Mixing Machine, previously referred to, two types being shown, together with a sectional drawing.

39 The Centrifugal Sand Mixing Machine consists of a rapidly revolving table, having on its upper surface a number of prongs. arranged concentrically. The sand is fed into the hopper at the top of the machine, from which it falls upon the revolving table and is thrown by centrifugal force from prong to prong and out against the inside of the cover or hood. It emerges from beneath the hood in a fine shower, free from lumps and thoroughly mixed.

40 The table, spindle, spindle pulley, and bearings are enclosed in the housing or base upon which the machine stands, so as to protect effectually these parts from sand and dust.

FIG. 4 CENTRIFUGAL SAND MIXER, BELT DRIVEN

41 A removable door is placed at the front of the housing to afford access to the spindle and bearings for cleaning or lubrication. The hopper can be lifted off for convenience of cleaning the prongs or removing stones, nails, etc., which do not pass between them.

42 The high rate of speed at which the table revolves, from 800 to 1200 revolutions per minute, causes the sand to be tossed with much force from prong to prong, thus breaking up agglomerated lumps of gravel or clay, insuring not only complete disintegration but a degree of mixing not attainable by any other method. Every

portion of sand is thoroughly "combed out," and analytical tests have shown the uniformity of mixture of heterogeneous compounds after passing twice through this little machine.

43 Fig. 4 shows a machine arranged to be driven by belt over the

FIG. 5 CENTRIFUGAL SAND MIXER, DRIVEN BY ENCLOSED ELECTRIC MOTOR

carrier pulleys at the back of the housing to the pulley on the table spindle.

44 Fig. 5 shows a machine driven by an electric motor enclosed within the housing where it is thoroughly protected from sand, dirt, etc.

DISCUSSION

Mr. E. H. Mumford As we all know, the mere handling of molding sand has a strange effect upon it. There are two classes of treatment, which, while not affecting its porosity, will vastly increase its strength. One is putting it through a reciprocating riddle, turning it over with a shovel, or otherwise throwing it about. The alternative treatment is rubbing the alumina in the sand into the silica.

2 In one of the classes of treatment involving the use of the scraper conveyor there enters another curious effect. In the scraper conveyor, turning the sand over always in one direction, there is a tendency to roll the particles of alumina up into balls, much as a snow ball is rolled along, gathering more snow; but under this treatment it has been common experience that more or less damage is done, as the speed of the conveyor is greater or less, the tendency being to cause the alumina to gather apart from the rest of the sand and the silica particles to be wiped clean of their coating of alumina, the result being that while you have all the constituents of a good strong sand, it has lost its bond and is practically worthless for many kinds of molding.

3 There is no question but that the Sellers centrifugal mixer is better than any other method of impacting or turning over and throwing together.

4 The experiments of Mr. Ronceray, which would doubtless prove of interest to members of the Society, consist of putting into an ordinary heap of sand a certain percentage of pure white silica sand, making the heap so rotten that it would not mold anything, and then rolling or rubbing that mass of sand on a plate with a hand roller. He takes six samples and gives each two minutes rubbing. After rubbing thus, the color of the first sample is gray; the next sample is less gray, and, finally, when you get to the sixth sample, it is practically the same color as the original heap. Every single crystal of silica has been coated with the dark alumina of the foundry sand. So, after twelve minutes rubbing by hand with an iron roller on an iron plate, the last sample is even darker and stronger than the original heap from which it was taken.

5 In our molding machine demonstration plant in Philadelphia we use ordinary heap sand for our demonstrations, and, as it never feels the heat of molten iron, it has been almost impossible to keep this sand weak enough to be a fair sample of molding sand. We have to keep adding silica sand to it.

Mr. H. M. Lane Mr. Mumford has brought out a point in regard to rubbing the alumina into the sharp silica to make the sand stronger which reminds me of a recent experience in a foundry in Ohio.

2 The foundryman was using a sharp, bank sand, mixed with a small amount that contained a little natural bond and a certain amount of core binder—a dry binder in this case—and had been discarding 50 per cent of the core sand and using about 15 to 20 per cent of the natural bond to make the mixture strong enough. He designed and put in a mill, which is essentially a clay grinding mill,

and grinds his core material. using 90 per cent of the old core sand. He finds that in the large cores the binder in the interior of the cores has not been so badly burned out but that it still retains a great deal of bonding quality, so that he now uses only half of the binder. He has thrown out all of the expensive imported sand and uses the local bank sand. He formerly had a power riddle and four men working all day to supply his foundry with core sand. Today he has a night force to haul the sand out, as formerly, but he has two men working less than half a day to supply the entire foundry with core sand. He formerly had to wheel the burnt core sand some 450 feet away from the foundry and dump it over the bank. Now he wheels it through a partition into the next room.

3 Counting the saving in time and labor and the saving in using a cheaper grade of sand, he figures that he has made over $2000 a year. In other words, he will pay for his mill in eight or ten months.

4 The foundry referred to is that of the Falls River and Machine Company, at Cuyahoga Falls, Ohio, and the mill was designed by Geo. H. Wadsworth.

5 In regard to the Worthington practice of grinding the bond in thoroughly, they found that they got the bond on the corners of the sand, if I may so express it, thus giving a very porous core, while if they mixed it by hand they got a much denser core. In other words. the venting of pockets and chambers gives less trouble than formerly because less compound was used and the pores were not being stopped up. They have been able to cast a great many very thin jackets in this way without any trouble at all even though vent passages were cut.

Mr. E. H. Mumford At a large foundry making steam pumps all the sand used in the smallest port cores is run through a mill. and with very good result. Nothing but raw linseed oil is used as a binder. The ratio of sand to binder is from 60 to 90 to 1. This very large ratio of sand to binder is entirely due to the rubbing in of the binder upon the small crystals of silica.

No. 1171

POWER SERVICE IN THE FOUNDRY

By A. D. WILLIAMS, JR., PITTSBURG, PA.

Non-Member

In view of the progress that has been made in other mechanical lines, it is remarkable that the foundry of today remains much as it was in the past. Since it plays a most important part in the industrial economy of all metal manufacturing plants, either directly or indirectly, it merits better treatment than it has received.

2 Some years ago the chemists turned their attention to the foundry and the results are seen in the replacement of empirical by scientific methods of mixing and melting and in the heat treatment of castings. The concrete results of their experiments are apparent in a reduction of the percentage of castings lost and the production of castings better suited to the purpose for which they were made.

3 The mechanical end of the foundry offers an interesting field for the engineer, not only in the designing of the castings, but in the invention of ways and means suited to their production. To a degree this work has been started, but has been confined to the production of molding machines and appliances, and the greatest progress has been made in those foundries which are devoted entirely to special lines of work, in which large quantities of castings of the same or similar characteristics are turned out. In the foundry whose output comprises a large variety of castings ranging from bench work to heavy housings and bed plates, the methods in use today differ but slightly from those of twenty years ago, the improved facilities consisting mainly in the provision of a better crane service for handling the work.

4 The principal reason why power is not used to a larger degree in foundry work arises from the fact that few foundries are so designed

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that the means at hand can be used to the greatest advantage. Machine molding is limited in its applicability to castings which can be turned out in sufficient quantities to justify fitting up for them. Power can be used for nearly all classes of green sand work, and once the proper fixtures for its use are available it will be found of service in many ways. The foundry crane of today is a vast improvement over that used in the past, but in the matter of improved crane service, not only the foundry but the machine shop as well, suffer a diminished output per square foot of floor area. Molding machines, cranes, chipping chisels, grinders, the blower and the cupola elevator are the usual limit of power service in the foundry. A few columns, roof trusses and siding, a crane with its runway, possibly a few jib cranes, a cupola with its charging platform, elevator and blower, some core ovens and a little industrial track are dumped down in a vacant lot and called a foundry. A rough neck carpenter knocks a few flasks together and sand is spread on the floor; just as soon as some pig iron, limestone and coke, etc., are delivered the plant is in running order. The machine shop is usually very carefully designed.

5 The crane service of a foundry is its vital point. There must be crane capacity to handle the heaviest piece to be made, but at the same time it is necessary to bear in mind the fact that there are a number of medium and a greater number of light pieces, to be turned out for each heavy casting. A single crane can serve only one floor at a time; the others must wait, in fact two or three floors are often waiting on the crane and must take their turns after the crane has finished handling a load of less than one-sixtieth of its capacity. This scene is not uncommon in the foundry, and that they were "waiting for the crane" is often the excuse for molds left over for the next heat.

6 The bridge traveling crane is a most useful machine but it cannot be in two places at the same time and as yet no successful method has been devised by which two of them can pass each other either on the same or on different levels, in fact the use of bridge traveling cranes on two levels only adds to the expense and does not supply any advantages over those cases where all of the bridge cranes are on the same level. The jib crane is limited in usefulness as it cannot serve floors outside of its radius, but a number of light column jib cranes, arranged so that they can be set up and transported from place to place as needed, are very serviceable. This can be accomplished by placing permanent pintle bearings on a number of the columns and by designing the jib cranes so that they

can be handled from point to point. The traveling wall crane affords the most satisfactory method of increasing the crane service without interfering with the bridge travelers above, and the column jib cranes below its level.

7 The electric motor offers the most satisfactory method of operating hoisting machinery. This arises from the convenience with which electricity can be delivered to these machines by means of sliding contacts. A further advantage lies in the close control of the movement which is essential to the gentle handling and accurate placing on the molding floor; another distinct advantage of the electric hoist is its ability to hold the load stationary for an indefinite time.

8 High hoisting speeds are undesirable, in fact the tendency is to get the hoisting speeds too fast in most shop cranes, high speeds being of service only in the handling of bulk materials and package freight. In the foundry a speed of ten feet per minute with full load is ample for heavy work and speeds exceeding twenty feet per minute are sufficient for the lighter hoists. Positive and uniform motion is necessary in handling copes and the sudden start of the ordinary air hoist spoils a great many molds. This sudden start occasionally occurs with electrically operated hoists having an improperly designed controller.

9 One of the important advantages of the electrical distribution of energy lies in the fact that only the exact amount of energy is transmitted and there are no stand-by leakage losses to cause expense. The occasional grounds which appear on the circuits can be taken care of readily and if the best modern methods of wiring are used, very little trouble is likely to occur from this cause. A good quality of insulated wire, run in some form of metal conduit, should be used; wooden molding should be avoided. The marine type of receptacles are most satisfactory for foundry service as the water-tight cover supplied with them is equally efficient in keeping out dust and dirt. These receptacles should be installed liberally as it is a great convenience to be able to get power just where it is wanted.

10 Another point of no small value is the kind of flexible connections supplied. These are often simply of lamp cord and are more or less of a nuisance, particularly when they get on the floor, where they are liable to be cut by a shovel, etc. Flexible metal tubing makes a first class protection for such connections, particularly for those which have to carry several horse power. Connections of this size will be required where portable tools are used.

11 There are a number of good makes of electric motors on the

market and some that are not so good. A first class standard motor is desirable, and in equipping a plant it is better to have all of the motors of one make, particularly those of the same size. A little attention to this point will greatly reduce the amount of money it is necessary to invest in spare parts. By a standard motor is meant one which has been made on manufacturing lines in large numbers. In addition to these there are a number of concerns building special motors more or less suited to their special requirements. The designers of such motors are handicapped by the fact that they are not able to avail themselves of the experience gained in the manufacture of a large and varied line. The street railway type of motor frame, or one which is split on an angle, having two poles or one pole in each portion of the frame is the most desirable, owing to the facility with which it can be opened up in cramped places for changing armatures or for other repairs. These motors are of the enclosed type and have been developed to work under conditions which would discourage the ordinary machine. The manufacturers of these motors often style them as "very rugged" which is an insult to the workmanship and designing ability which has developed these desirable types of machines. Another feature of such motors is the method of lubrication, in which the car box journal has been studied and improved. Lubrication is often neglected by careless operatives and while any machine is better for a little attention, these motors will stand up under poor conditions.

12 Molding machines are generally operated by compressed air, but hydraulic power is used with some machines. Compressed air is elastic and this is a disadvantage for many operations, as any alteration in the load causes a corresponding change in the position of the actuating plunger or piston. Some compressed air hoists have been designed with a governor device that regulates their speed of action, but it is impossible to avoid the troubles due to the elasticity of the air. Another disadvantage of compressed air machines is the large size of the hose connection required, which is more troublesome to care for than the smaller flexible connection to an electric motor. Compressed air however is very useful in cleaning out pockets in molds and for power ramming machines; for the latter it presents the only successful driving power. These machines are not as widely used as they might be, and where it is desirable to avoid the long air hose connection, a portable motor driven air compressor can be used. The bellows and torch, for blowing out and skin drying the sand, can be avoided, the former by using the air hose with special nozzles, the latter by arranging some sort of a heating device close to the air

hose nozzle. An electric heating device might be serviceable for this purpose.

13 As generally installed, with a central compressing plant, the use of compressed air requires an expensive transmission line and in addition, it is impossible to avoid leakage in the joints. Compressed air leakage does not show, and the pipe lines for this purpose, as usually constructed, are designed to remain tight only long enough to pass the acceptance test. Leakage is a continuous drain on the system, and shows up in the amount of coal consumed. Except in the large sizes, air compressors are steam eaters like steam pumps; for this reason the small electric driven air compressor presents numerous advantages, as it consumes no power when out of use and, if portable, avoids the long pipe line. The disadvantages of long air lines are well illustrated by the fact that in some of the big excavating contracts it has been found very advantageous to install a steam driven electric generating station at a point where fuel was available from a railroad siding, and transmit electric power to the compressor station located on the work, thus avoiding the losses of a long pipe line or fuel haulage.

14 Hydraulic power is but rarely used in the foundry. It has advantages for some lines of work. Water being non-elastic, comparatively speaking, it supplies a positive pressure, and while the hydraulic machine can be stalled, it is impossible to break it by legitimate methods, when it is properly designed. The pressures carried in hydraulic systems range around 500 and 1000 pounds per square inch; where higher pressures are required in certain machines they are obtained by the use of intensifiers. The most serious disadvantage of hydraulic service systems occurs only where swinging joints are required to convey the pressure and waste water to and from moving machines, as cranes, etc. In the machines themselves the glands are like all other glands, troublesome to maintain, and are often pulled up so tightly that they greatly reduce the efficiency. The controlling valves also give a certain amount of trouble. The most of the trouble with hydraulic systems arises from the use of dirty, gritty water. An illustration of the advantages of using a clean fluid occurs in the hydraulic wheel presses in which the same fluid is used over and over again. These machines cause very little trouble from leaky glands. High pressure hydraulic systems are however expensive to install, and it is extremely probable that the best method of utilizing hydraulic power will be to use an electrically driven pressure pump with its accumulator installed close to the floor upon which hydraulic molding machines are to be used. This

would reduce the required amount of pressure and waste line to a minimum. Necessarily this small hydraulic plant could not be placed in the foundry itself but a small pump room would be a requisite.

15 Steam power was at one time the only motive force available and was either transmitted to those places in the foundry where it was required by means of belts and shafts, or small engines were used, driving the different machines by belts. In some cases small gas or other explosion motors are used in a manner similar to the early steam motors. Owing to the fact that small engines are not economical and have several other disadvantages which are familiar to all who are posted on foundry operating conditions, they are not considered as desirable as other kinds of motors. The steam hydraulic crane and elevator, both of which operate on the same principle are two of the most satisfactory machines devised for foundry service, because they are very simple and for that reason it is practically impossible for the most careless operator to damage them, except by the most studied neglect. One of the bad features of any transmission system which deals with moist elements such as water, steam and sometimes compressed air, exists in their liability to damage in cold weather by freezing. This danger has to be very carefully guarded against in temperate and cold climates, during the night and on all occasions when work is interrupted. To guard against this trouble some form of heat insulation is required.

16 As to which is the best power to adopt, depends in a large degree upon the local conditions affecting the plant, and by studying such conditions much better results can be attained than are possible by offhand decisions. A harmonious installation works more smoothly than a miscellaneous assortment and, in addition, the design should take into account the future growth as a possibility, this matter being often left out and resulting in endless complications when extensions have to be made. Because the largest part of foundry power requirements are intermittent, it is extremely probable that electrical methods offer the most economical solution of the question, but against this the question of maintenance is often of more importance than the economy of operating expenses due to cheaper power.

17 The class of labor employed in many foundry operations is not possessed of any amount of mechanical skill or electrical knowledge, and for this reason it is advisable that the motive power portion of the equipment be as nearly "fool-proof" as possible and of the simplest possible construction in order that it may not be damaged by misdirected zeal. The use of electrical power necessitates the

employment of one or more men to look after the motors, depending upon the number used, or else a considerable portion of the minor repairs must be made by outside help. Where the foundry is operated in conjunction with a machine shop, the matter of maintenance becomes more simple. With steam, compressed air or hydraulic machinery, the question of maintenance is not of such a complicated character as with electrical machinery, owing to the fact that it is much easier to get men who have some primary ideas and break them in to the small repairs required to keep the machines in operating condition. And with the exception of the most extraordinary break downs, such machinery can be restored to working order by the use of the facilities ordinarily available in the vicinity of a foundry. This however is not always the case in regard to electrical machinery, though since the uses of electrical machinery are extending so rapidly, a time will be reached when the question of repairs will be as simple as it is with other types of motors.

DISCUSSION

MR. FRANK RICHARDS Mr. Williams' interesting paper challenges remark in one particular. He says: "With a central compressing plant, as generally installed, the use of compressed air requires an expensive transmission line, and, in addition, it is impossible to avoid leakage in the joints."

2 For line piping for compressed air transmission, precisely the same pipes and fittings are used as for steam or water, and it is no more difficult to make joints tight, and to keep them tight, for air than for steam or water. In fact it is much easier to keep air pipes tight than steam pipes, as the same heating and cooling, with their accompanying expansion and contraction stresses, do not occur.

3 It might be well for Mr. Williams to go to the Pennsylvania Terminal excavation about West Thirty-third Street. He will find there considerable lengths of compressed air pipes running all around the excavation, with branches reaching in various directions to hoists, pumps and rock drills; and if he can find any leaks there, he will do what the writer has not been able to do.

4 At the Phillipsburg shops of the Ingersoll-Rand Company all the power transmission is by either electricity or compressed air. There are some miles of compressed air pipes, and various air operated devices are employed both in the foundry and elsewhere, and the pressure left in the pipes at night is found in them next morning.

5 The quarry of the Cleveland Stone Company at North Amherst, Ohio, has nine or ten miles of compressed air pipes, all the machinery of that extensive quarry being air driven, and there the piping is "bottle tight."

6 Mr. Williams states further that "compressed air pipe lines, as usually constructed, are designed to remain tight only long enough to pass the acceptance test." The compressed air business, just like the other established lines of manufacture represented by hundreds of members of this Society, has grown and has prospered, not by the passing of acceptance tests, but by all-the-year-round efficiency and reliability after acceptance.

7 In this connection it seems to be permissible, if not imperative, to call attention to a record of compressed air practice which is unique. For supplying the compressed air by whose agency the various tunnel enterprises of Greater New York have been carried so nearly to completion, there have been installed, all of them being still in place, eighty air compressors. The combined free air capacities of these compressors amount to 190 000 cubic feet per minute, which volume would be represented by a cube with a side of 57 feet. They develop an aggregate of 40 000 horse power.

8 These compressors, as they were erected, were almost immediately put to work, and if there was any acceptance test in any case, the ceremony was generally omitted. The compressors have worked constantly, most of them day and night, and always some on Sundays, at speeds never before recorded, and with life and death dependent upon their maintenance of the working pressures; conditions of unusual difficulty and many of them unforeseen and unprovided for have developed; there have been accidents and delays innumerable in the progress of the work; all these we have heard of, but not one word of any shortcomings of these compressors.

9 The work of building these tunnels, as is well known, was done under the direction and approval of some of the world's most experienced and responsible engineers and by several different contracting companies, but every one of these eighty compressors was built by the same manufacturing company. The acceptance test may be said to have been in the completion of the entire task, and its triumphant accomplishment is in sight.

10 Again, we are told that "except in the large sizes, air compressors are steam eaters like steam pumps." The steam driven air compressor of any size is normally a stationary steam engine with its power applied directly to the work of compression; and for steam consumption and power development it is always comparable upon

equal terms with the ordinary stationary engine of the same type. It may have a plain slide valve with suitable lap, it may have an adjustable cut off, or it may be a completely automatic engine with Corliss or equivalent valve gear; and we may in every case expect the same economy in the compressor as in the stationary engine. The ordinary steam pump of any size has clearances large and uncertain, but certainly large, and it uses the steam entirely without expansion; so that the pressure at the end of the stroke is as high as the highest. Its piston speed is slow; it is comparable only with itself.

MR. E. H. MUMFORD I think that no one will accuse me of favoring hydraulic power rather than compressed air; I have too many compressed air molding machines in stock that I would like to sell; but the undoubted fact is that a leak in a compressed air system is very subtle, hard to detect, and generally neglected, often becoming serious. I presume many of you have had experience with feeding oil to the air end of an overloaded compressor. It is astonishing how it increases the delivery of leaky valves. If someone would originate a dry air valve for compressors that would work satisfactorily without leakage, the efficiency of a compressor plant would be very much increased.

2 I am not condemning compressed air nor air compressors. They are absolutely essential in a great deal of our work, perhaps in the majority of it.

MR. RONCERAY[1] I desire to say a few words in favor of water pressure. I have had experience with it, especially in connection with molding machines, and I have also had experience with compressed air in the pneumatic tool business.

2 I do not agree that it is more difficult to keep a water line tight than it is to keep a compressed air line tight. Indeed, I think the difficulty that might happen is that in many cases the air line has to be made very big in size as compared with what is really necessary in a well designed system of hydraulic pressure. We very seldom use a pipe line larger than half an inch in diameter, even for large molding machines, and under these conditions we have never found any trouble in keeping a water line tight.

3 The practice that we have followed in Europe in molding machines is to use copper pipes, which are easily bent to suit conditions, instead of iron pipes with all their numerous joints and elbows.

[1] With the Universal System of Machine Molding, Philadelphia, Pa.

The joints are therefore much less in number than in an iron pipe air line. I have never found any difficulty in keeping a half-inch copper pipe line tight.

4 Another point: there is no reason why a valve, in hydraulic service, cannot be designed so as to be tight. We have a valve, designed for water, which gives entire satisfaction. It is impossible to keep a metallic seated valve tight. The only way to keep a valve tight is to use leather packing; the trouble in hydraulic valves having leather packings is generally that the leather is scratched in passing the ports; the valve we have designed is similar to a poppet valve with a leather seat, and in our practice, when we use good leather packing we never have a leak.

5 It is very easy to make this experiment. If you have a reservoir in which your compressed air is stored and leave it charged at night, the following morning you are pretty sure to find the pressure down; while it is quite common, with a hydraulic accumulator left at a certain level at night, to find it at the same level the following morning.

Mr. J. E. Johnson, Jr. The writer wishes to confirm what was said about the ease of keeping air lines in order. At the plant of the Princess Furnace Company, Glen Wilton, Virginia, there is an air line five inches in diameter and 8000 feet long. No trouble whatever has been experienced and it has been in operation for over a year. Long sleeve couplings and expansion joints were put in at intervals to take care of changes in temperature.

2 The old theory that air is harder to hold than steam is a technical untruth that has been circulated long enough. If steam starts to leak, it will eat almost like an acid, and can never be made tight. Whereas with air it is only necessary to tighten the joint that is leaking. The constant working from expansion and contraction caused by variation in temperature with steam makes it much more difficult to keep tight. This is aside from any consideration of condensation losses.

3 The statement in Mr. Williams' paper that it has been found profitable to put in an electric transmission in big excavation work the writer does not believe will be borne out by practical experience. Running through the calculation in this very case shows that the cost of electrical transmission, outside of the engine, would be about $12 500, while the cost of the pipe line was only $1500. Counted roughly, the cost of the compressor would be about the same as that of the power engine, for the reason that the compressor required in the

steam cylinder about 160 horse power; and to deliver the same amount of air at the same point with the electrical apparatus would require 250 horse power, giving a net efficiency of 87 per cent, against only about 56 per cent. Furthermore, the initial cost was three or four times as much for electricity.

4 The proposition to transmit by electricity and then transform the energy into compressed air will not work on a commercial scale for distances short of five miles.

MR. S. D. SLEETH[1] In the Westinghouse Air Brake Company's foundries both air and water are used. Water is used on certain machines at a high pressure (1300 pounds), which permits the use of a very small cylinder. If air were used on these machines it would require a much larger cylinder. Leaks can be discovered in a water line where they would not be noticed in an air line. It is much easier to keep an air line tight than to keep a water line tight, for there is not the pressure and the expansion and contraction in cold weather.

2 The principal reason for using water in these foundries is on account of its small volume and positive action.

MR. H. M. LANE The locomotive crane has not been given sufficient attention in the foundry. There have been a great many attempts to get some system for taking the flasks in and out of a foundry to and from the flask storage. The writer is of the opinion that all light flasks should be stored under shelter. Of course large flasks and heavy rigging can frequently be stored in the open to advantage.

2 In many cases the traveling crane runway is extended through the end of the foundry so as to cover a portion of the yard. This is impracticable in this Northern climate, where serious effects upon the health of the craneman may result from running out over the yard in zero weather with insufficient protection from the cold. In case of resulting illness the substitution of a new man necessarily retards the work, which is expensive.

3 Then, too, whenever the crane runs out through the end of the foundry, practically the entire end of the building has to be removed, and particularly the upper part where there is the hottest air. As a consequence, the heat all goes out and the zero weather comes in. The next effect is that the men all leave their work and congregate around the salamanders, so that the expense of running the crane

[1] Non-member, superintendent of foundries, Westinghouse Air Brake Company, Wilmerding, Pa.

through the end of the foundry may be very great. In fact, it may virtually result in the stopping of practically all work for several hours on days when the end of the building is open a great deal.

4 To overcome this difficulty, several foundries have run a track down through the middle of the building. The locomotive crane then enters the building through a comparatively low door, without letting all of the hot air out.

5 This crane can bring carloads of flasks and distribute them along the floor wherever they are wanted. The long boom of the locomotive crane will frequently be convenient as an auxiliary crane on special work. In fact, it is serviceable both indoors and out, enabling the foundry management to accomplish vastly more than could be done without its service.

6 When a locomotive crane goes out of doors flasks can be piled just as far as the boom will reach. When the yard is full, space can be rented somewhere near. When the locomotive crane service is installed there is no expense for overhead runways, as in the case of traveling cranes, the only outlay is for railroad track, which may also be used for shifting cars.

7 In a mining enterprise, in which the writer engaged some years ago, it was necessary to deal with various kinds and types of pipe lines, 2000 or more feet long. Among other difficulties, there were those due to expansion and contraction, insulation, and hidden joints. In one mine there were about 30 or 40 miles of air pipe lines running from central stations. Air was carried over mountains to another mine, and on that line, which was several miles long, air was sometimes left on the line over a holiday and at the end of 48 hours the pressure had not fallen over ten pounds.

8 No difficulty was found in keeping those long lines practically tight with compressed air, with a variation of temperature of from 50 degrees below zero in winter to 110 degrees in summer. Therefore there should be no difficulty in keeping the air mains tight in a foundry.

9 What Mr. Ronceray says about the hydraulic lines is true. In the course of investigations a few years ago, of installations of hydraulic power in a large number of steel works, the writer was surprised at the tightness of their lines, due perhaps to the small diameter of the pipes and the care with which the joints were made.

The Author Mr. Richards has called my attention to the fact that main compressed air lines can be made tight and kept tight; but there are many cases where they are not kept tight. A large leakage occurs in nearly every compressed air system in the connections made to the various driven machines, particularly when these connections are of a temporary nature. Undoubtedly leakage in a compressed air line and in all of the machine connections can be practically prevented, but it is very rarely done.

2 I should have qualified my statement that "compressed air lines, as usually constructed, are designed to remain tight only long enough to pass the acceptance test." I did not have the kind of acceptance test in mind which is usually associated with this expression, but the rough and ready test made in the field by the pipe fitter, or the erecting man. Such tests are much more frequent than those of a purely scientific nature.

3 Mr. Richards and I evidently have different ideas as to what constitutes a small compressor. Compressors dealing with less than 60 to 70 cu. ft. of free air per minute do not have Corliss valve gears.

4 In the class of service to which Mr. Richards has alluded, subaqueous tunnel work, reliability in a compressor carries far greater weight than steam or power economy. A saving of five to ten pounds per hour in steam consumption during several years would not make up for the damage resulting from one enforced shut down of the air compressor lasting any considerable time.

5 Mr. Mumford's remarks I agree with, in all particulars. Mr. Ronceray's remarks are interesting and his observations have been confirmed in my own experience.

6 In regard to the relative economy of compressed air or electric transmission: Mr. Johnson doubts the economy of such transmissions for less than five miles. In this the individual case has so much to do with the cost of construction that it would be easy to assume conditions or to find conditions where electric transmission would be the more economical, or the reverse. Aside from economy of operation and construction there are many cases in which a small electric driven air compressor, merely by its convenience and the ease with which it can be carted around and operated, would be far ahead of the pipe line system of getting the air to the work.

7 Mr. Lane has spoken of the locomotive crane. This machine should be better known in the foundry, and as it can be utilized as a shifting engine in addition to the numerous ways Mr. Lane has suggested, it merits some attention. The locomotive crane renders the foundry man independent of the delays of railroad switching service around his own plant. My reply to Mr. Richards covers the points in regard to compressed air lines mentioned by Mr. Lane.

[illegible]

No. 1172

A FOUNDRY FOR BENCH WORK

A Description of the New Foundry of the Michigan Stove Company

By W. J. KEEP and EMMET DWYER,[1] DETROIT, MICH.

Member and Non-Member, respectively

On January 8, 1907, nearly the entire works of the Michigan Stove Company were destroyed by fire. Reconstruction was begun at once and by July 1 of the same year, the new plant was entirely completed, having been built on modern lines, substituting alternating electric current and individual motors for belts, shafting and rope drives.

2 On account of poor light, and lack of good ventilation on hot days, it was difficult to get molders to work in the old foundry. The new works, although surrounded by high buildings, are comfortably cool on the hottest days, and the temperature does not rise much during pouring. Fifteen minutes after the heat is off, the foundry is clear.

3 Before deciding on plans for the new works the writers visited several foundries, and found that of the American Stove Company at Bedford, Ohio, best suited to their needs. This plan was accepted with the modifications of an extra row of windows in the roof, and three monitors running crosswise instead of lengthwise.

4 The roof presents some new features as adapted to foundries. A small model was constructed in which an extra row of windows was placed at each side, in the central part of the slope, and the outer edge of each roof section raised to give the usual pitch of a gravel roof.

Presented at the New York Meeting (December 1907) of The American Society of Mechanical Engineers, and forming part of Volume 29 of the Transactions.

[1] Second Assistant Superintendent, the Michigan Stove Company, Detroit, Mich.

FIG. 1 INTERIOR VIEW OF THE FOUNDRY

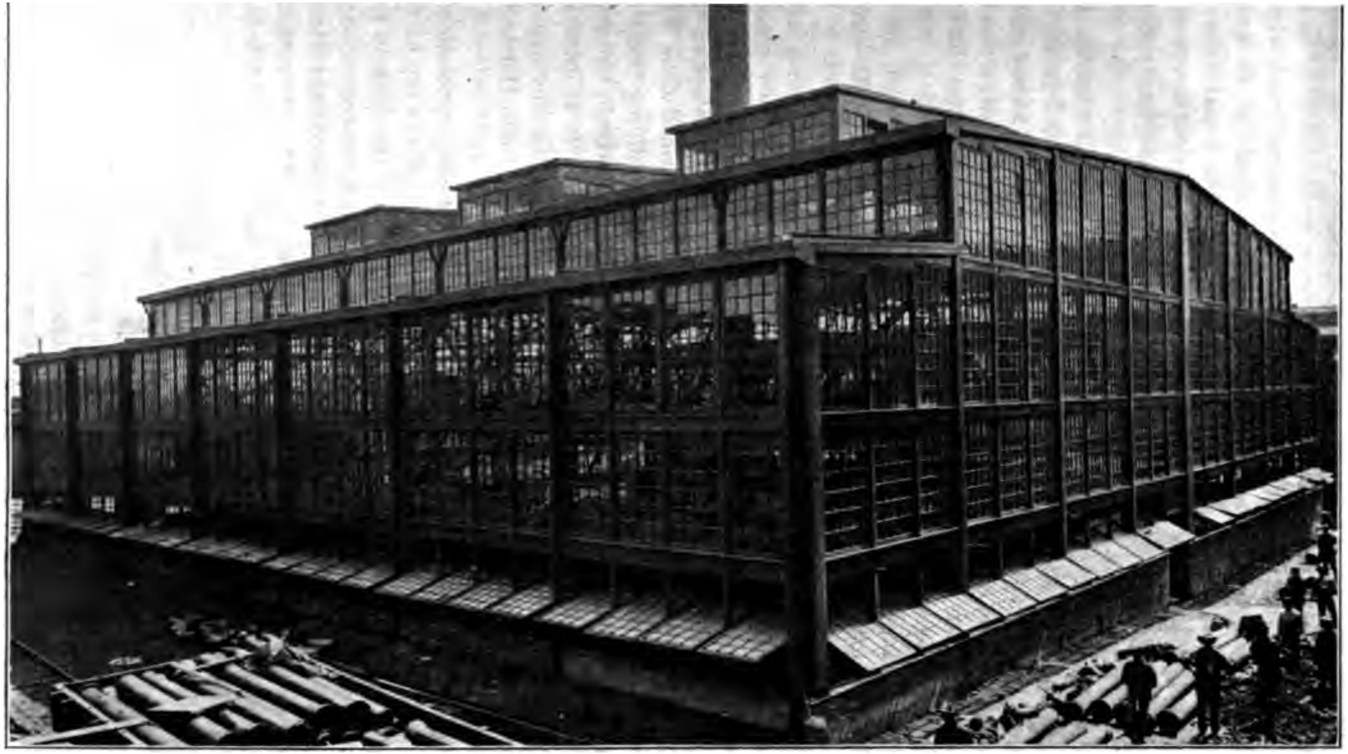

FIG. 2 EXTERIOR VIEW OF THE FOUNDRY

5 This arrangement allowed the windows in the roof to be 10 feet high, and another row 10 feet high was added on each side, which permitted the use of the ordinary gravel roof, instead of the usual felt roofing with cinders. The disadvantage of the usual form of roofing with the latter covering is that its steep slope does not permit of its being walked upon. The ordinary gravel roof has proved entirely practicable for the purpose.

6 The foundry is 128 feet square; the other dimensions are approximately, 50 feet to the top of the monitors; 40 feet to the highest point in the roof proper, and 30 feet to the roof at the sides. The girders are on 18 foot centers. As an economy in cost, a row of posts was used in the center, instead of having one truss the full length of the span.

7 The foundations are of concrete, the walls, 6 feet high, are of brick 12 inches thick, the balance is constructed of steel, with a roof of 2½ inch matched pine.

8 The building is so nearly fire proof that it is not considered necessary to install sprinklers. There are hydrants at two places, and fire hose with 100 pound water pressure. There are no wooden partitions or wood work other than that covering the steel at the windows—which the architect, being more used to wood than steel construction, insisted upon using to make the building weather proof—and the charging platform, the framework of which, however, is steel with mill construction floor 8 inches thick. It is intended when the wood is perfectly dry (for the purpose of guarding against dry rot) to cover the upper surface with sheet metal and the under surface with some kind of fireproofing.

9 The height of 30 feet at the sides of the building is to allow a deck to be erected at some future time on the line of the top of the first row of windows. The present plan is to begin the deck 10 feet away from the side windows, making it wide enough to accommodate one row of molders, with a gangway at the edge toward the center of the foundry. The under side of the deck will be 12 feet from the foundry floor, and the deck floor about seven feet from the underside of the lowest member of the truss.

10 The floor is of brick, laid in cement. One corner, 18 by 60 feet, is used for a core room, and besides there is ample room for 86 bench-molders.

11 It has not been found necessary to open the monitor windows, it being cool enough when they are closed, but every second window can be swung open. All of the others are stationary except the bottom row, where each window swings open.

12 Some difficulties were met in removing the cupola from the old location to its present site, a distance of 45 feet. It has a 72 inch shell, is 75 feet high, lined to the top, and is estimated to weigh 76 tons. The local movers were asked to submit bids, the lowest of which was $600, and there was no competition for the order even at that price. Finally a house mover agreed to move it for $175. There was no guarantee against accidents in any case.

13 The company furnished $\frac{5}{8}$ inch wire rope for four guy ropes, which were fastened at their outer ends by tackle, and provided the men to manage them.

14 Two timbers were placed under the cupola from front to rear, and one crosswise. These and the cupola were raised with ordinary movers' jack screws until 5 inch wooden rollers and timbers to roll on were placed beneath. A cross timber was fastened by chains on the under timbers, and jack screws between this cross timber and the ends of the timbers and directly under the cupola shoved the cupola along.

15 To insure its being kept plumb, a timber projected from the charging platform door, from which a plumb-bob was suspended by a wire. A plank fastened to the base of the cupola with a nail driven so that its head was directly under the point of the plumb-bob, told which way to raise the blocking. After everything was ready the cupola was moved in ten hours. The mover made a profit of $75, and the entire cost to the company was $225.

16 The foundry will be heated by the forced circulation of hot water, which is to be kept at 157 degrees. The temperature at zero weather is guaranteed to be 45 degrees. The radiation is estimated at 4300 square feet of radiating surface, using $1\frac{1}{2}$ inch pipe.

DISCUSSION

Mr. E. H. Mumford The authors have mentioned that they have a mezzanine floor and placed the machines under, instead of on it. This is especially interesting in view of the fact that just now a modification of what has come to be known as the Crane system of placing machines and everything else on the upper floors, and dropping castings and sand down through perhaps several floors, is being exploited in a number of new foundries. I should like to know their reason for putting the machines *under* the mezzanine floor.

The Authors The 12 or 14 ft. that we have under the floor is ample room for molding machines and it seemed to be better to put them there. We want a carrier that will not occupy too much room in height and that will take a flask from the molding machine and shoot it clear to the other end of the floor and bring a mold back and shake it out at the machine.

2 I might say that we did not intend to manage everything automatically as Mr. Mumford seems to infer.

No. 1173

SPECIFICATIONS FOR IRON AND FUEL AND METHOD OF TESTING FOUNDRY OUTPUT

By R. MOLDENKE, WATCHUNG, N. J.

Member of the Society

Although one often hears of the fine castings produced by the numerous smaller foundries, where specifications and analysis for purchase and sale are disregarded, mention is seldom made of the carloads of castings rejected on account of excessive hardness or internal sponginess. These foundries generally employ standard material, which can be spoiled only through ignorance. In special lines of foundry work, however, and in the large jobbing shops, iron and other supplies are purchased under specification and are subjected to careful inspection.

2 A comparatively simple set of specifications for all foundry supplies—pig-iron, fuel, fluxes and the newer ferro-alloys—will insure ample results. Since cast iron is primarily a steel with varying carbon content, carrying large amounts of impurities and mechanically mixed with graphite, it follows that a wide range of metal for casting purposes may be secured by varying the proportions of the impurities and of the combined and free carbon. Thus, a cast iron with but 0.20 per cent of combined carbon and near 4 per cent of graphite will really be a "twenty" carbon steel, the graphite merely causing the metal to act like cheese under the tool. The addition of steel scrap to the original mixture—thereby reducing the percentage of graphite without materially altering that of the combined carbon—strengthens the metal, which now, however, will not cut so readily under the tool. Proceeding farther, an increase in combined carbon and a reduction in graphite, secured by reducing the silicon, will produce an "eighty" carbon steel, with so little lubrication for the tool as to be too expensive to machine.

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3 In this way by varying the proportions of combined and free carbon, a wide range of metal is obtained, beginning with the soft, weak, easily machined black iron, rich in graphite, running through the gray and mottled grades, and ending in a hard strong white iron susceptible only to being ground.

4 Since the relative proportions of combined and free carbon may in a great measure be controlled through the silicon, it is generally sufficient to specify the maximum allowable percentages of sulphur, phosphorus and manganese. Normally blown irons, from reputable blast furnaces, run so uniform in carbon content as to render specification unnecessary. An "off cast" renders itself quickly apparent through the other impurities, and is sold only under its true designation.

5 For ordinary machinery castings (gray iron) the pig-iron used as part of the charge should contain:

Sulphur, not more than 0.05 per cent
Phosphorus not more than 0.50 per cent
Manganese not more than 0.80 per cent
Silicon, from 1.75 per cent to 2.75 per cent, as specified.

6 For malleable castings (white iron) the pig iron used should contain:

Sulphur, not more than 0.04 per cent
Phosphorus not more than 0.225 per cent
Manganese, not more than 0.60 per cent
Silicon, from 75 per cent to 1.50 per cent as specified.

A variation of 10 per cent, either way, from the above figures may be allowed.

7 Where light castings are desired, as for stoves and art work, the phosphorus is specified at 1.00 per cent and over, and the silicon often as high as 3.25 per cent. Similar specifications may be prepared to cover the rest of the thirteen rather distinct grades of cast iron, with their more than forty variations.

8 To enable foundrymen unacquainted with the metallurgy of cast iron to buy intelligently, the American Society for Testing Materials, through its committee on specifications for foundry iron, prepared schedules designating the composition of the very deceptive but well known, old grade numbers. Thus No. 1, 2, 3 and 4 are to contain 2.75, 2.25, 1.75 and 1.25 per cent of silicon, respectively, fracture appearances being disregarded. Sulphur is specified at less than 0.035, 0.045, 0.055 and 0.065 per cent, respectively, when estimated volumetrically, with an allowance of one hundredth more in case the gravimetric method is employed. A variation of 10 per

cent of silicon either way, from the above figures is allowed; and the sulphur may vary 0.02 per cent. A deficiency of over 10 and under 20 per cent does not lead to rejection, but entails a penalty of 4 per cent in price. This is eminently fair, and protects manufacturer and foundryman alike.

9 In sampling, each car is taken as a unit, and from this one pig is selected out of each four tons. In case of dispute, a pig is selected from each two tons, the loser paying for the additional labor caused by the closer sampling. Drillings from these pigs taken so as to fairly represent the fracture surface, are to be well mixed before analysis.

10 It is interesting to note that the liberality of these specifications, appealing as it does to the conservatives, is in direct contrast to the severer requirements of the foundryman who buys by specifications of his own.

11 Ordinary foundry operations require as fuel anthracite, coke and soft coal, while producer gas, natural gas and oil are employed in the special brass furnaces and in the "Open Hearth" for steel and high grade iron. Necessity for specification is confined to bituminous coal and coke, and in the case of the former only the sulphur, and occasionally the ash, demands attention. The increasing use of the air furnace for the manufacture of high grade engine castings is leading to a study of the availability of various soft coals; and the United States Geological Survey, through its advisory board on fuels and structural materials, has gathered much information, so that specifications for coal and coke for melting purposes may be expected soon. In the meantime, it may be stated that no coal containing more than 2 per cent of sulphur should be used in the foundry, and, preferably, the amount of this impurity should be limited to 1 per cent. Similarly, the ash should be limited to 10 per cent.

12 The employment of coke demands closer attention to moisture, to the remaining volatile matter, fixed carbon, sulphur, ash and sometimes phosphorus. Usually, however, the sulphur, ash and fixed carbon are sufficient to give a fair idea of the value of coke, apart from its physical structure, specific gravity, etc. The advent of by-product coke will necessitate closer attention to moisture. Bee-hive coke, when shipped in open cars where it absorbs much moisture, may, through inattention, cause the purchase of from 6 to 10 per cent of water at coke prices.

13 Concerning sulphur, there is much to be ascertained; whether its sulphates or its volatile compounds get into the iron, and how. Foundry practice, however, has recognized the fact that a very hot

running of the cupola results in less sulphur in the iron. In good coke, the amount of sulphur should not exceed 1.2 per cent; but, unfortunately, the percentage often runs as high as 2.00. If the coke has a good structure, an average specific gravity, not over 11 per cent of ash and over 86 per cent of fixed carbon, it does not matter much whether it be of the "72 hour" or "24 hour" variety. Departure from the normal composition of a coke of any particular region should place the foundryman on his guard at once, and sometimes the plentiful use of limestone at the right moment may save many castings.

14 Limestone to be used for fluxing should be as rich as possible in carbonate of lime, for each unit of silica transformed into slag exacts its equivalent of lime and coke. Oyster shells form a most desirable flux, and fluor-spar tends to thin the slag.

15 Use of the modern ferro-alloys will eventually be limited to the richer grades. Even today 80 per cent ferro-manganese is demanded; and, while 50 per cent ferro-silicon is much used, the 75 per cent grade, or better, is specified by the wide awake foundryman. It is wasteful to employ a rich alloy in the cupola; but in the ladle, removed from the further application of heat, the smaller bulk of the richer alloy causes a smaller reduction in the temperature of the molten iron. For the present, specifications are not required for these alloys, which are made from the best material, and should be low in the undesirable elements, sulphur and phosphorus.

16 In selecting scrap iron, each foundryman chooses worn out or broken castings similar in composition to the proposed product, so that the addition of this scrap to the pig-iron mixture does not disturb the calculations.

17 Beyond the exclusion of burnt or very dirty metal, and of sizes so small as to cause waste in melting or too large to enter the charging door, specifications for scrap iron should be limited to a statement of the class of material wanted—machinery, malleable wheels, pipe, etc.

18 Weak castings and castings with pin holes or with pockets under the skin are indicative of the use of burnt metal. Three hundredths of 1 per cent of oxygen in solution in the iron as an oxid or combination of oxids is, in the case of white irons, sufficient to ruin them completely. The excessive "skulling" of ladles, and other troubles, can be traced to this cause. Thus oxygen in cast iron is far more powerful than even sulphur; yet the action of the former is little understood and does not lend itself readily to chemical investigation.

19 In the matter of molding sands, American foundry practice is

far behind that of Germany, or of the rest of Europe. Until the price of our sands has advanced considerably, we shall continue to wet down and mix with a shovel, instead of grinding and sifting and tempering by mechanical means, as in foreign practice. Careful preparation of the sand before it goes to the molding floor will insure castings free from surface blemishes. Under present American conditions, attempts to introduce specifications for molding sands are of doubtful value.

20 The absolute necessity, in the case of a successfully operated steel foundry, for the application of specification to all supplies purchased is so well understood that the steel foundry is usually classed with the steel mill, and apart from the foundry. If the acid process is used, or the Bessemer converter, the metal used is a "fancy" pig iron containing practically only iron, carbon, and the proper manganese and silicon. The basic process allows the use of cheaper material.

21 The characteristics of the finished product are determined either by testing each article, or by testing to destruction an occasional sample, or by the use of test bars.

22 If the establishment makes finished specialties in iron, ease in machining is the important requirement, and an estimate of this quality may be gained by placing an occasional cast sample disk in the lathe or drill press, the nature of the tests being dictated by the experience of each shop.

23 Ordinary commercial castings, on the other hand, must be subjected to additional tests: boiler sections, to determine their resistance to pressure; valves, to ascertain whether or not they are tight. Castings produced in very large quantity must be tested to destruction, by sample, which of course, is far beyond the limits of actual service conditions. The remarkable quality of car wheels has resulted from this exacting system of testing.

24 The foundryman, however competent, is dependent upon the quality of the iron for the production of serviceable castings. It is necessary therefore, in the many cases to which testing to destruction is inapplicable, to make a test of a sample form composed of iron identical with that in the casting. Today in foundry practice the foundryman may employ shop test bars of such size and shape as he chooses. Comparison of the performance of his test bar with that of the purchaser's test bar will enable the experienced foundryman to determine the degree of exactness with which he is meeting the requirements.

25 Finding that such a variety of standards prevailed, the Ameri-

can Foundryman's Association and the American Society for Testing Materials, under separate action but by individual members of each committee, have adopted a set of specifications which embodies the last word on this complex subject. These specifications depart entirely from established procedure.

26 It has been attempted in these specifications to avoid the introduction of outside influences as far as practicable, and to have the sample represent accurately the iron as it comes from the cupola or the furnace. Hence, the round sample bar is to be of as large size as the limits of commercial testing machines will permit; it is to be poured in a vertical position, to avoid the difference of strength between top and bottom, if poured horizontally; and the mold is to be dried, to ward off the effect of damp sand. The speed of testing is specified, and a regular routine of pouring is to be observed. At the suggestion of Mr. Walter Wood, this bar is called the "arbitration bar," as it is intended for use only in case of dispute between buyer and seller.

27 The new method of testing, as adopted by the American Society for Testing Materials, is being generally used, and is found to be far superior to the old custom of flat, square bars of small cross section, or the long bars so susceptible of dishonest manipulation. The transverse is best suited to the peculiar nature of cast iron; but an optional tensile test is provided for, at the cost of the party demanding it, although in Germany this latter test is excluded altogether. For further details, the reader is referred to the publications of the two societies mentioned heretofore.

28 The ethics of the cast iron industry has been dependent upon the better understanding of its metallurgy. In times past the foundryman refused orders to which specifications were attached and he refused even to provide tentative specifications which might enable the buyer to obtain such iron as he desired to purchase. Now this is changed, and the progressive foundryman welcomes inspection of his methods and tests of his product.

29 It is to the lasting credit of the foundry that the first demand for specifications came from the foundrymen themselves, through their Association, and that they coöperated heartily with the engineer by furnishing information, freely and without reserve, A very friendly feeling between buyer and seller has ensued; for no better evidence of good faith can be given than an invitation to visit freely the shops and the laboratory to inspect manufacture and test. This is the rule today, not the exception.

No. 1174

FOUNDRY CUPOLA AND IRON MIXTURES

By W. J. KEEP, DETROIT, MICH.
Member of the Society

THE CUPOLA

Iron for ordinary castings is melted in a cupola, a vertical brick lined cylinder, in which are charged coke and iron in alternate layers, while air is forced in by a blower.

2 The leading kinds of cupolas have the same general proportions which leave little room for improvement; by measuring a large number of cupolas, before any type had become common, and tabulating records of melting, the writer determined that proportions exert almost no influence upon the melting efficiency. The results depend rather upon the skill or care of the melter.

3 A special form of cupola is described in this article; but so far as details of construction are concerned, there are as many opinions as there are designers, and as good results are claimed with other forms.

4 It does not pay to purchase a small cupola. A 72-inch shell may be lined with common red brick next to the shell and with fire brick inside to bring the inside diameter right—say 36 inches for a small business, to be increased as the business grows. Above the charging door the ordinary 5-inch lining may be used.

THE LINING

5 Every test the writer has made has shown that for ordinary melting of gray iron the cheapest stock brick may be used to good advantage.

6 Square bricks should be used wherever possible, and key or arch bricks only when necessary to turn the circle without leaving spaces between. A stock brick, whether square, split, key or arched,

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18 The shape or number of the twyers is not of great importance, but the usual construction is of cast iron, bolted to the shell, and of a size to admit enough air to burn the coke in the shortest possible time. The admission of air depends on the friction in the blast pipes at the twyer openings and the blast pressure at the twyers, and the size should be calculated for about eight ounces pressure.

19 It is usual to keep the top and bottom twyer walls nearly horizontal. The sides, however, should be flared toward the center of the cupola to compensate for the partial choking of the admission of air by the fuel and chilled slag lying directly in front of the twyers. The overhanging bosh, described above, helps to form a continuous air chamber and prevents clogging, by melted iron and slag, all around the cupola in front of the twyers, thereby insuring a gentle and even admission of the blast that does not injure the lining. By giving a slight inward flare to the openings, the twyer casting can be made with a green-sand core, but they may be made so wide at the inner end that they nearly or quite touch each other. One or more supports are cast near the inner openings to prevent the top of the twyer from sagging. The shape must be such, however, that when melted iron accidentally rises and chills, it can be pushed out without injury to the twyer.

20 A very good way to form a practically continuous twyer is by means of plates or segments one inch thick, and equal in width to the thickness of the lining at the twyer circle. When the lining is built to within an inch of the blast openings in the shell, a circle of the segments is laid on it. Cast iron blocks 3 inches wide and 4½ inches high are placed on this even with the front of the circle and about seven inches apart. Another circle of segments is laid upon these blocks and then the regular brick lining is continued. This construction leaves a 3-inch continuous space unbroken by partitions, next to the shell, and permits the air to enter at all points with equal force.

THE BOTTOM

21 The bottom is made of sifted sand from the gangway, dampened, tempered and riddled. The sand should be shoveled in through the breast and stamped with the feet, and then rammed as in molding. Make a close joint around the edges, and have the sand at least 2½ inches thick above the cupola bottom at the level of the spout lining, (not the bottom doors) and with a level and straight edge make it slope up toward the back ½ inch in each foot.

22 If the bottom is too wet, or is rammed too hard, it is liable to lift up and crack and let the melted iron cut through the bottom doors. To prevent this accident, drill the doors with ½ inch holes 4 inches apart, so that the steam and gases from the sand bottom can escape.

THE BREAST AND TAP HOLE

23 To make the breast, hold a board against the inside of the cupola and ram from the front a mixture of one-third part fire clay, and two-thirds burnt molding sand wet with clay-wash and tempered with new sand.

24 Form the tap hole with a smooth stick, 15 inches long and tapering from a diameter of 2 inches as one end to 1 inch at the other, laid in the breast with its small end against the board. When the breast is rammed full, remove the board, shove the stick in two inches and scrape away the breast at the front to an arch until at the tap hole it is only 1 inch thick.

Operation

CHARGING AND RUNNING

25 In a 72-inch cupola use about four bushels of shavings, and spread some over the bottom and pile them up around the sides to the twyers, in front of which lay shavings and splinters. Then lay kindlings evenly over the whole bottom and set soft cord wood on end all around the sides, with some short pieces in the center.

26 For the bed charge 1200 pounds of coke, and light the fire at the twyers and at the tap hole two hours before the wind is to be put on. Build a wood fire all along the spout (which has been lined one inch thick with the same mixture as the breast) and light the fire in front of the breast, leaving the twyers and tap hole open until the coke is well ignited. After the wood is all burned out, close the twyer doors and charge on 500 pounds of coke. Bend the ends of a rod, at right angles, in opposite directions, of such length that when the upper end hangs on the charging door sill, the lower end will be two feet above the top of the twyers. Add enough coke to reach up to the lower end of the rod, and spread evenly on this coke one-half of the first charge of pig iron and scrap, and 100 pounds of coke, then add the other half charge of iron. This makes 1800 pounds of coke on the bed, and 4800 pounds of iron consisting of 3200 pounds of pig iron and 1600 pounds of sprues and scrap (for stove plate).

All the rest of the charges consist of 250 pounds of coke and 3000 pounds of iron. (1950 pounds pig and 1050 pounds of remelt).

27 Scatter over each charge of coke two shovelfuls of screenings from the gangways, and two of limestone, broken as small as an egg. Continue charging until full to the charging door. If the fire is lighted at 12 m. the charging should begin at 12.30 p.m. and the wind put on at 2 p.m. Stop the tap hole at 2.10, and tap out at 2.15. With 20 charges (31 tons) the wind should be off at 5 p.m. Fuel ratio 9 to 1, and the melting 10 tons per hour. (Cupola 72 inch shell).

THE BLAST

28 Fast melting fuel must be burned rapidly. With free entrance for air and with a positive blower the speed of melting can be increased by increasing the blast up to 18 ounces pressure. No further increase of speed in melting is obtained with 22 ounces pressure and with 26 ounces the melting will be slower, showing that more air is blown than can be used. About 14 ounces is the best pressure for any kind of blower or cupola. When speed is not required, a lower pressure, (perhaps six or eight ounces) may give more economical results.

29 As good results are obtained with one kind of blower as with another. Those who use a positive blower think they get a stronger blast, but it does not pay to change if the blower already in use is large enough.

ADVANTAGES OF HOT IRON

30 Iron should be melted hot, whether it is to be poured hot or dull. Hot iron is fluid, and gases and slag can separate and castings will be even in grain and free from blow holes.

31 It is important to have a hot cupola before the iron begins to melt. Whether the cupola is small or large, the fire should be lighted two hours before the iron is needed, and the fuel should be well lighted all over the center before the iron is charged.

SLAGGING

32 Slag should be drawn off and not allowed to reach the twyers. The slag hole is a 4-inch square hole left in the brick lining opposite the tap hole with its top about 4 inches below the bottom of the twyers. It is lined and its upper end is stopped with daubing clay. Slag should be allowed to accumulate until it is nearly up to the twyers as it protects the melted iron from the blast and strains

out the dirt. Before the slag runs out of the twyers the slag hole is opened just enough to let the slag run as fast as it forms. By arranging a trough, a crust will form, covering the hot stream beneath; and by raising the crust a little with a bar it will set and form a channel which will keep a steady stream of slag flowing with no noise or escape of wind.

SAVING IRON FROM THE BOTTOM

33 A way to save iron dropped from the bottom of the cupola which has been found better than a cinder mill or any separator is as follows: After the wind is off and all melted iron has run out of the cupola, make a circular dam of sand about four feet in diameter in front of the cupola and about four inches high. Lay a tapping bar across the spout and with a piece of 1½ inch shafting 8 feet long ram in the breast and let all of the slag run out on the floor. The iron will settle under the slag. When the slag is all out, drop the bottom, wet it down and draw it out. In the morning, there being no slag, the bottom can be picked over by hand. All iron is thrown to one side, and any piece of sand bottom, or of slag not containing iron, is discarded. All coke large enough to use is saved; and all small coke and iron is shoveled up and taken to the scaffold, to be thrown in, with all skulls and sweepings containing iron, when the last charge has settled some distance down. The small coke holds down the blast, improving the last melting, and drops again with the bottom. The cupola is so hot that this iron is fit for use for almost any casting.

FUEL RATIO

34 For heavy machinery castings and car wheels, with large cupolas, and when the iron need not be as hot as for small castings sometimes 18 pounds of iron are melted with 1 pound of coke, counting in the bed and not deducting iron or coke dropped with the bottom. For ordinary castings it is not economical to run any risk of having dull iron, because the loss of castings would be greater than any saving of coke.

35 For stove castings, for which the iron must be as hot as for any work, a fuel ratio of 9 to 1 can be maintained constantly with a 72-inch cupola, using a coke bed of 1800 pounds and melting 30 tons in 2¾ hours. To obtain such a ratio it is not necessary to break the pig iron, but all scrap should be broken as small as the pig iron, so as not to leave voids. The coke, pig and scrap must be charged uniformly. It is better to charge one row of pig iron flatwise around

the circumference, then another row inside of this, and so on until the center is filled. One ton of pig iron will make about one thickness all over.

36 Stove plate, sprues and scrap weighing half a ton will take more room than the pig iron and 260 pounds of coke will completely cover the iron charge. The charge for stove plate will be 250 pounds of coke, 1950 pounds of pig iron and 1050 pounds of remelt. On the bed the iron charge is 3200 pounds of pig and 1600 pounds of scrap, and the regular charge of 3000 pounds of iron and 260 pounds of coke then continues through the heat.

37 Greater economy can be obtained if the coke is reduced on the last three charges, and sometimes the cupola will be so hot that the last charge can be melted with very little coke. The smaller the coke charge the faster the melting, provided sufficient coke is used to melt the iron hot. For fast melting, care and cleanliness are essential; no dirt or dust from the charging platform must be shoveled into the cupola, as it will prevent the iron from settling evenly.

QUALITY OF THE COKE

38 The quality of the coke is one of the most important things in iron melting, because the iron is in constant contact with the fuel. Coke should contain about 10 per cent of ash so as not to crush by the weight of the iron, or break up by the heat. If it contains too much volatile matter it will melt and clog the cupola, but the percentage of volatile in good and bad coke varies so little that it cannot be determined by analysis.

39 The sulphur should not exceed 0.75 per cent, but very often amounts to 1 per cent and over. It is estimated that with 0.75 per cent of sulphur in the coke 0.03 per cent will enter the casting; and as the sprues and bad castings are remelted each day it is difficult to keep the sulphur in the castings below 0.08 per cent, which is the limit. In machinery scrap and stove-plate scrap sulphur is estimated at 0.08 per cent. Therefore if the coke contains more than 0.75 per cent of sulphur it is very difficult to use scrap enough to give a close grain without exceeding the above limit and thereby causing hard spots and blow holes in the casting.

40 Since the great demand by blast furnaces for beehive oven coke, it has not been as reliable as when the founder could refuse a car load which did not give good results. Retort oven coke can be made of uniform quality and it is very satisfactory, but does not look as well as beehive coke.

THE FLUX

41 Limestone is the best flux, and in a slight degree lessens sulphur; but its chief use is to make the slag fluid enough to run out of the slag hole, and to keep the cupola clean especially when the bottom is dropped.

42 It is a question whether the special fluxes on the market do as much good as claimed, but they are worth a trial. Fluor-spar is more efficient than limestone, but is more expensive.

IRON MIXTURES

CHEMICAL COMPOSITION AND PHYSICAL QUALITIES

43 It is physical quality that the founder requires, and he would not trouble himself about the chemical composition were it not that by varying it he can vary the physical quality to some extent.

44 By decreasing sulphur, or by increasing silicon, the casting will be made softer. By decreasing sulphur, or by increasing silicon, or phosphorus, or both, fluidity is increased, and the iron is grayer and has less shrinkage. By increasing the manganese the sulphur is decreased or rendered less harmful.

45 But the physical quality of the iron charged, the conditions under which the iron is melted and the manipulation of the fluid iron also materially influence the physical quality of the casting, irrespective of the chemical composition.

PIG IRON

46 Close grained and strong pig-iron is likely to make castings having those characteristics. The close grain is generally accompanied by low silicon and sometimes by high sulphur, but it may have been caused by the original smelting conditions, *i.e.*, whether the blast furnace was cold or hot. Close grain in a soft casting generally means that it is strong, but for the closest grain and the greatest strength the casting is generally as hard as can be tooled.

47 Another reason for using close-grained, low-silicon pig-irons, and pig-irons low in phosphorus, is that they set more quickly, thereby preventing internal shrinkage and porosity. Large castings cool slowly; the interior is fluid a long time after the exterior has become solid, and contracts more and more as its temperature lowers, so that when its center reaches the freezing point there is not enough bulk to fill the space. In solidfying it crystallizes on the crystals

already formed, resulting in a very loose grain at the center; and finally, as the last iron becomes solid, a true cavity is left. Thus we have a shrink hole surrounded by a spongy iron. By feeding hot fluid iron to such a center through a channel which is kept open by churning with an iron rod, every part of the casting can be made solid.

48 By using northern irons made from Lake Superior ores the tendency to sponginess is lessened because they set quicker than southern irons. Or if an iron chill can be placed in the mold in a wall very near the spot that would otherwise be spongy it will set the metal quickly and prevent the trouble.

THE SCRAP

49 Castings made from scrap iron of the same general size and grain as is desired in the casting and cast under practically the same conditions may be expected to have a similar grain—or a tendency toward a closer grain which would require to be offset by the addition of a small amount of a more open pig-iron.

50 An unduly coarse grain in the scrap will close up somewhat in remelting, or close-grain pig iron may be used with it. Small, close-grained scrap, remelted for making a large casting which cools slowly, having a relatively higher silicon will have a coarser grain.

51 Scrap is not ordinarily analyzed, though it often constitutes one half the total mixture. Silicon runs 1.50, 2.00 and 2.40 per cent in heavy, medium, and small soft scrap, respectively, and the sulphur is about 0.08 per cent.

52 In selecting scrap for a mixture, throw out all wrought, burnt, malleable and chilled iron, and all steel.

53 Stove-plate scrap is very close grained, with sulphur about 0.08 per cent and silicon about 2.75 per cent. For machine castings it closes the grain and adds strength, but its silicon is not as effective as in pig iron because of its high sulphur and rather low carbon. The loss in weight during melting is excessive.

54 Select machinery scrap the size of the castings to be made, and break it small enough to melt in the cupola as fast as the pig-iron.

QUALITIES OF IRON PRODUCED

55 Following are chemical compositions and physical qualities desirable in irons for various kinds of work, and some mixtures that will give them.

HARD IRON FOR HEAVY WORK

56 Castings for compressor cylinders, valves, high pressure work, etc.

57 Chemical composition: Si 1.20 to 1.50 per cent; S under 0.09 per cent. P 0.35 to 0.60 per cent; Mn 0.50 to 0.80 per cent.

58 Physical qualities: Transverse strength of a test bar 1 inch square and 12 inches long, 2400 to 2600 pounds; tensile strength of same bar 22 000 to 25 000 pounds; shrinkage in yokes, 0.160 inch; chill in yokes, 0.25 inch.

59 Mixtures: Steel scrap to the amount of 10 to 25 per cent may be added in the cupola. In a foundry running both air furnaces and cupolas, for castings of over 15 tons, one half of iron from each may be mixed in the ladle to give strength. When the amount of steel exceeds 10 per cent a very small quantity of aluminum should be used in the ladle to increase fluidity. It will remove all gases, prevent blow holes, and give a very close grain. A piece of pure aluminum wire $\frac{3}{8}$ inch in diameter, and 1 inch long, for each 100 pounds of iron, is sufficient; do not use so called "casting aluminum." To insure a perfectly sound interior, make large castings as hard as will allow of machining, by keeping the silicon as low as possible. Select close-grained foundry iron low in silicon, or mill iron if the grain of the foundry grades is too coarse. A close grain in pig-iron accompanies a higher sulphur content which is due to a cold furnace. Charcoal pig-iron gives a close grain with low sulphur.

60 Although using scrap closes the grain, use it sparingly for the strongest castings—sometimes not more than 10 per cent, to avoid introducing sulphur. It is safer to use close-grained pig, and steel scrap. For extra strength, use 1 to 10 pounds of ferro-manganese, either in lumps in the cupola or granulated in the ladle.

61 The best way to close the grain and prevent sponginess is to charge 100 pounds of cast-iron borings with each ton of the mixture packed solid in a covered wooden box six inches deep. The box settles down to the melting point before the wood burns, and then the borings melt and mix, without more than 10 per cent loss. Steel borings and chips can be used instead, but aluminum is needed in the ladle. Do not mix cast iron and steel borings in the same box.

62 In calculating mixtures for heavy castings, allow 1.50 per cent silicon and 0.10 per cent sulphur to be contained in the scrap.

MEDIUM IRON FOR GENERAL WORK

63 Castings for low pressure cylinders, gears and pinions, etc.

64 Chemical composition: 1.50 to 2.00 per cent; S under 0.08 per cent; P 0.35 to 0.60 per cent; Mn 0.50 to 0.80 per cent.

65 Physical qualities: Transverse strength of a test bar 1 inch square and 12 inches long, 2200 to 2400 pounds; tensile strength, 20 000 to 23 000 pounds; shrinkage 0.154 inch; chill 0.15 inch.

66 Mixtures: No. 1, 2 and 3 foundry iron. Home and foreign scrap up to 50 per cent of the whole is allowable for the best castings; or more with carefully selected scrap. In calculating mixtures, allow 1.75 to 2.00 per cent silicon and 0.10 per cent sulphur in foreign scrap.

SOFT IRON

67 For general car and railway castings, pulleys, small castings, and agricultural work.

68 Chemical composition: Si 2.20 to 2.80 per cent (with less the castings are hard, and with more they are too weak.) For large castings, 2.40 per cent is a good average; S under 0.85; P under 0.70; Mn under 0.70.

69 Physical qualities: Transverse strength bar 1 inch square by 12 inches long, 2000 to 2200 pounds; tensile strength 18 000 to 20-000 pounds; texture, to close the grain use as high a percentage of scrap as will give soft castings.

IRON FOR FRICTIONAL WEAR

70 Castings for brake shoes, friction clutches, etc.

71 Chemical composition: Si 2.00 to 2.50 per cent; S under 0.15 per cent; P under 0.70 per cent; Mn under 0.70 per cent. The addition of spiegeleisen increases hardness.

CALCULATING THE COMPOSITION OF AN IRON MIXTURE

72 A variation in silicon will make castings either hard or porous. The grain of the pig and the fracture of scrap are generally reproduced in the casting. The seller of pig-iron will give a close approximation to the chemical composition of his iron. The ordinary founder will not employ a chemist to make exact determinations.

73 Whether the founder uses the approximate or the accurate determination of his irons, he should calculate the chemical composition of his mixture.

APPROXIMATE CALCULATION

74 Make up on paper the desired mixture, using irons in stock and figure from the analysis, or estimate, of each pig-iron, the previously calculated composition of the home scrap, and the estimated composition of the foreign scrap. Multiply the pounds of each iron used by its percentage of silicon to obtain the pounds of silicon, and divide the aggregate weight of silicon in all the irons by the total weight of iron used, thus obtaining the percentage of silicon in the mixture. Deduct 0.20 per cent for loss in melting. The remainder is the silicon in the casting; and if this is too high or too low to produce the desired percentage, vary the irons and figure again; and so on until you secure a mixture that will be satisfactory.

PRECISE CALCULATION

75 To arrive at the composition by one calculation: If you are forced to use certain irons, determine their weights by considerations of economy, or of stock on hand (for example, enough home scrap to prevent accumulation; enough foreign scrap to cheapen the mixture or to close the grain, and the desired pig irons) and compute the total silicon as before. Then adjust the percentage of silicon in the mixture by calculation from two pig irons, one lower and the other higher in silicon than the percentage just computed, as shown in the following example.

76 An actual stove-plate mixture was desired having 3.50 per cent silicon in a charge of 3000 pounds. The chemist's analysis card had accompanied each car of pig iron. In this case no foreign scrap was used.

	Weight in pounds		Per cent Silicon		Pounds Silicon
Home scrap	900	×	3.25	=	29.25
No. 1 foundry	400	×	2.50	=	10.00
No. 2 foundry	350	×	2.18	=	7.63
No. 3 foundry	250	×	1.53	=	3.82
	1900				50.70
	3000	×	3.50	=	105.00
Needed	1100	×	4.94	=	54.30

77 That is, we needed 1100 pounds of an iron having 4.94 per cent silicon to balance the mixture.

78 We had in stock No. 1 soft with 2.95 per cent silicon, and Ash-

land silvery with 7.00 per cent silicon; which balanced for the 4.94 per cent as follows:

		Differences		Balances	Total Parts
4.94	No. 1 soft	2.95	−1.99	206	405
	Ashland silvery...............	7.00	+2.06	199	

1100 ÷ 4 05 = 2.72 pounds = 1 part.
206 × 2.72 = 560 pounds of No. 1 soft needed.
199 × 2.72 = 541 pounds of Ashland needed.
Take 550 pounds of each to make even weights.

79 This example will fit almost any foundry condition. The result can be checked by computing the silicon in each iron as follows:

550 × 2.95 = 16.225
550 × 7.00 = 38.50
1900 = 50.70

3000 × 3.51 = 105.42

80 Allowing loss of silicon 0.20 gives 3.31 per cent silicon in the casting. The actual analysis was 3.34.

81 If, on the other hand, you have plenty of each of the irons in stock and do not care what proportions you use, calculate as follows:

	Differ-ences	Balances					Parts	Total parts
Home scrap 3.25	−0.25	350					350	
No. 1 foundry..........2.50	−1.00		350				350	
No. 2 foundry..........2.18	−1.32			350			350	2259
No. 3 foundry..........1.53	−1.97				350		350	
No. 1 soft..............2.95	−0.55					350	350	
Silvery 7.00	+3.50	5+100+132+197+55					509	

3000 pounds = 2259 parts. 1 part = 1.328 pound.

Iron	Parts	Weight
Home scrap................................	350	464.8 pounds
No. 1 foundry..............................	350	464.8 pounds
No. 2 foundry..............................	350	464.8 pounds
No. 3 foundry..............................	350	464.8 pounds
No. 1 soft..................................	350	464.8 pounds
Silvery.....................................	509	676.0 pounds
Total..		3000.0 pounds

82 But you can only weigh differences of fifty pounds, so divide the 3000 into multiples of 50. If you wish to do so, use 650 pounds of home scrap.

Proof

$$\begin{array}{r}
650 \times 3.25 = 21.125 \\
450 \times 2.50 = 11.25 \\
450 \times 2.18 = 9.81 \\
450 \times 1.53 = 6.88 \\
450 \times 2.95 = 13.28 \\
650 \times 7.00 = 45.50 \\
\hline
3000 \times 3.59 = 107.84
\end{array}$$

Losses in Remelting

LOSS OF IRON

83 The following is the only reliable published data on remelting losses of which the author knows:

84 In a cupola lined to 52 inches one ton each of several different irons were melted at one time with the results given below. No iron was thrown away, and the data are reliable.

Kind of Iron	Pounds loss per ton	Per cent
A No. 1 Cherry Valley Pig (Si 2.70 per cent S 0.015 per cent)	95	4.75
B Cleaned new stove plate	159	7.95
C Cleaned sprues from stove plate	130	6.50
D New stove plate with sand on	230	11.50
E New sprues plate with sand on	280	14.00
F Old stove plate scrap (rusty)	227	11.35

85 By pickling with hydrofluoric acid it was found that 33 pounds of the 95 pounds loss of *A* was sand purchased on the pigs. Milling a ton of *F* just as purchased showed that 50 pounds of the 227 pounds loss was rust.

Taking results from *A* to *F:*

	Loss pounds per ton	Per cent
The calculated loss from a 37 ton heat (72 inch cupola)	116	5.80
The actual loss from a 37 ton heat (72 inch cupola)	88	4.41

In a small cupola with small heats the loss would be relatively greater.

MEMORANDA FROM THE 37-TON HEAT 72 INCH CUPOLA

Shot iron recovered from the gangway	26 pounds per ton melted
Good sand recovered from the gangway	111 pounds per ton melted
Coke recovered from the bottom	57 pounds per ton melted
Slag tapped out	207 pounds per ton melted
Sand on pig from pig bed	30 pounds per ton melted
Limestone used as flux	43 pounds per ton melted

TEST BARS ½ INCH DIAMETER BY 12 INCHES LONG

	Strength	Shrinkage
37-ton heat stove plate	380 pounds	0.149 inches
Remelted cleaned stove plate	390 pounds	0.162 inches
Remelted cleaned plate sprues	375 pounds	0.158 inches
Remelted old stove-plate scrap	377 pounds	0.202 inches
Remelted No. 1 Cherry Valley pig	410 pounds	0.149 inches

86 In large stove foundries the sprues and plate lost in pouring are charged into the cupola with sand on, it being cheaper to melt the sand than to mill it off; hence the large amount of slag. In machine foundries the gates and lost castings being more bulky, the loss in remelting would be less than in a stove foundry.

87 Boiling of the first iron on the cupola bottom and in the green ladles is likely to form a white core and gray surface in the first castings; therefore pour unimportant work with the first 500 pounds.

LOSS OF OTHER CONSTITUENTS

88 By remelting, carbon is very rarely increased, and is generally decreased; more of it is in combined form than before because the cupola is not as hot as the blast furnace, and because the sulphur is increased.

89 Silicon decreases about 0.20 per cent; sulphur increases about 0.03 per cent; phosphorus remains constant; and manganese decreases about 0.15 per cent; when in the casting it is 0.50 per cent.

90 By using percentages of sulphur, phosphorus and manganese as in the proof, we can find the percentages of these elements in the casting. The object of varying the chemical composition is to control the shrinkage, hardness and grain of the casting, and we must test these physical qualities to ascertain the result of the chemical variation.

91 For the mixture first calculated, a test bar ½ inch square by 12 inches long gave a strength of 430 pounds; shrinkage 0.126; chill 0.06, and hardness 23 degrees.

The analysis was: T C 3.43, CC 3.27, GdC 0.16, Si 3.15, P 0.958, S 0.055 per cent.

MECHANICAL ANALYSIS

92 Turning the above the other way, we find that a shrinkage of 0.126 resulted from 3.15 per cent silicon. We also know that a decrease of silicon increases shrinkage and vice versa; therefore, if the shrinkage rises above 0.126, we must increase the silicon by using more of some iron high in silicon to bring it back, and if it drops below 0.126 we can use more scrap or hard irons, thereby decreasing the silicon and cheapening the mixture.

93 This regulating the silicon from the physical end is a mechanical analysis; and it is the only one, since shrinkage is the only physical quality that varies with a variation of silicon. Mechanical analysis is quick and inexpensive. It can be used by any founder and goes directly to the spot without any chance of mistake.

DISCUSSION

MR. G. R. BRANDON Having had many years experience in the manufacture of the Whiting cupolas and being in constant touch with operators of these cupolas, Mr. Keep's paper has been of especial interest to me. I desire to comment on several points he raises:

2 Cupola linings commonly consist of backing brick next to the shell, blocks 4½ inches or 6 inches thick forming the inside lining, coming in contact with the heat and having to withstand the abrasive action of the stock in descent from charging door. The blocks are usually of volume equal to about 3 "square" bricks, and prices are practically the same, the volume being considered. In setting lining the work may be accomplished more quickly and cheaply with blocks; and, on account of the fewer joints exposed to the action of the heat, inner linings last longer when composed of blocks than of the same quality of "square" and arch brick.

3 The usual instructions to operators of cupolas are to maintain inside walls of linings vertical and cylindrical in section from bottom plate to charging door, and to pick out slag attached to brick before each heat and apply daubing mixture. The simplicity of this procedure is its greatest recommendation; but, as safety from "hang-ups" is assured if cupola is operated properly in other respects, the very doubtful benefit derived from reduced bosh and enlarged melting zone may be disregarded.

4 Twyers may be located so that any suitable quantity of molten metal may be accumulated in the cupola before tapping. In the converter processes for steel castings iron is first melted in cupolas

and it is usual to collect the entire amount for a charge in the cupola before tapping out, the twyers being set to permit this accumulation.

5 The lower the twyers, the less the amount of fuel on the bed and the greater the economy. It must be remembered, however, that fuel in bed serves the purpose of heating up the cupola and sufficient must be charged to accomplish this result, whatever the height of twyers.

6 The standard twyers of Whiting cupola are flaring, the opening at the inside of lining being wide, horizontally, and comparatively narrow, vertically. The adjacent twyers in the lower row almost meet, practically forming a complete annular inlet.

7 One frequent cause of "run-outs" through bottom doors is the use of overhanging linings. The sand of the bottom not being tucked properly under the projecting lining at all points, the molten metal cuts through in a weak spot. In this emergency a tap hole should be opened, all molten metal drained out and a stream of water directed on the hole through the bottom to "freeze it" Plugging the hole with clay will allow the completion of the heat.

8 For cupolas with 84-inch shell, and larger, a mechanical charging machine can be used and the labor of charging greatly reduced. Records show that two men with this machine can charge a cupola melting 18 to 20 tons per hour, whereas, without the machine, five or six men would have been required.

9 I have never known of records of actual operation, showing as high a ratio of iron to fuel as 18 to 1. This would be practically impossible with our wheels. Mixtures for car wheels are low in silicon and, consequently, the molten metal lacks fluidity and must be very hot when tapped, and poured quickly. Steel is now generally used in car wheel mixtures and this requires more coke. Pigs and large scrap are generally considered to require more fuel than broken pigs and smaller scrap. We have a record covering eleven months operation in which over 13 000 tons were melted for car castings, the ratio of iron to fuel being to 10.31 to 1. These results have always been considered excellent.

Mr. E. H. Foster In an issue of the Engineer of London, March 23, 1900, is a description of a cupola liner which was later patented in the United States under serial number 651 703.

2 While visiting a foundry in London where the liner was developed, the owner took me up to the charging floor of a cupola which was being cleaned, and asked me to guess the material forming the lining. On looking down through the charging door the internal

surface of the cupola was perfectly clean, free from any projections, of a grayish-white color, and divided off into squares resembling tile. It was difficult to tell just what the material of the lining was. It resembled somewhat an enameled tile in appearance and was much too clean and unbroken to be fireclay.

3 As a matter of fact the lining was made of cast iron, built up in hollow blocks of radial brick form. It was claimed that it had been in use for 19 months, and that the cupola, which was a No. 5 Stewart Rapid, was formerly rated at four tons per hour, but that after lining with the cast iron hollow bricks five tons per hour were easily gotten out of it.

4 Besides increase of capacity there was a saving in time for repairs, also in the use of ganister. The perfectly smooth surface prevents all tendency to hang-up, and after each run the surface can be swept clean. Furthermore, there is no danger of such a lining becoming broken by the charging process. It seems that such a lining can be easily applied to almost any type of cupola.

5 Several cupolas in England are so lined, but I do not know of any in this country.

Prof. W. W. Bird It has been the writer's experience that many questions are asked in regard to the use of scrap in foundry mixtures. One point that has not been brought out is this: we understand that silicon is used in foundry mixtures for the purpose of making castings soft for machining. In the paper it is stated that it is best to select the scrap according to the thickness of the castings to be made. In selecting scrap it is a very simple matter to specify that the material should give some evidence of having been machined, and that, if this evidence is present, then the percentage of silicon must be somewhere near the proper amount for that thickness. This test should be included in the specifications. Then we will have something that will correspond to the chemical analysis.

The Author So far as the walls of the cupola are concerned, most of the cupolas in the market are straight and very much alike. I simply presented this construction as one that has done good work. I know that those who used the straight wall cupola get just as good results. I will change the melting ratio in my paper from 18 to 10 to 1.

2 Answering Professor Bird's remarks in regard to the scrap, I agree with him if it could be done. If a piece of scrap is about the size of the casting, and of the grain that you expect the casting to have, remelting the scrap will close the grain, partly on account of the

sulphur that is in it, and partly on account of the low heat used in remelting.

3 There seems to be a great variety of opinions among foundrymen as to the practical use of borings. It is a matter of fact, however, that all who have endeavored to close the grain of iron and prevent sponginess have found the use of cast iron borings successful. It was a patent process by Mr. Whitney, the car wheel manufacturer, but the patent has expired and it is now public property. It seems to be one of the suggestions that always helps the foundryman out of trouble.

4 In regard to the recovery of the iron from the borings, they should be treated in the way which Mr. Whitney suggested. Pack them in boxes holding 100 lb., nailing the cover on tight, and then charge them just the same as 100 lb. of iron. It is obvious that the boxes will reach the melting point without being burned, and when they reach the free oxygen the wood will burn off and the borings will come out in small quantities and there will be very little loss. I presume about 10 per cent would be the maximum loss and sometimes it would be less.

5 Answering Mr. Smith's inquiry in regard to a one-inch bar: It will be difficult to reply to the question except in a general way. The strength per square inch of a test bar is in proportion to its size, that is, to its rate of cooling. An inch square bar is stronger proportionally than one or two inches square; the exact relations between the strengths cannot be arrived at by the formula ordinarily used.

6 At the meeting in Chicago in 1904 I presented a table which is not only interesting, but is very useful, giving multipliers and divisors by which the strength of bars of different sizes can be calculated.

7 As to casting a test bar vertically or horizontally, my impression was that a test bar cast vertically was stronger than when cast flatwise. The experiments made by our former testing committee, however, showed the contrary to be true.

8 Several years ago I was asked by a Western university to make a number of test bars for them to determine the influence of aluminum which we added to our iron and I cast them vertically, supposing it would give them more strength, and then in order to have the test bars look well, I put them in a tumbling mill and made them smooth. The result was that those test bars proved to be so strong that I never heard the result of the tests. I found out afterward, however, by Mr. Outerbridge's experiments, that the tumbling of cast bars, or the tumbling of any other casting, increases the strength of the material perhaps 25 per cent.

No. 1175

FOUNDRY BLOWER PRACTICE

By WALTER B. SNOW, BOSTON, MASS.
Member of the Society

Modern foundry practice in the melting of metals is fundamentally dependent upon the blower. As the successor of the blowpipe and the bellows, it has made possible the massing of fuel in large quantities, with greater imposed resistance, the production of higher temperatures, and the better utilization of the heat in the furnace.

2 The primary function of a blower is to move air against resistance. Its performance is dependent upon the relation expressed by the formula:

$$V = \sqrt{2gh} \qquad [1]$$

in which V = velocity in feet per second
h = head in feet
g = acceleration due to gravity = 32.16

or
$$V = \sqrt{2g\frac{p}{d}} \qquad [2]$$

when h is expressed in terms of p = pressure and d = density.

3 When applied under the conditions of

p = pressure in ounces per square inch
d = density or weight per cubic foot of dry air at 50

degrees fahr. and under atmospheric pressure of 14.69 pounds or 235 ounces = 0.077884 pounds, formula [2] becomes

$$V = \sqrt{64.32 \times \frac{p \times 144}{16 \times 0.077884 \times \frac{235 + p}{235}}} \qquad [3]$$

Presented at the New York Meeting (December 1907) of The American Society of Mechanical Engineers and forming part of Volume 29 of the Transactions.

which reduces to

$$V = \sqrt{\frac{1\,746\,659 \times p}{235 + p}} \qquad [4]$$

Allowance is evidently made therein for compression of air but not for change of temperature during discharge.

4 The velocities in the basis Table 1 were calculated by this formula.

5 The tabulated volume is in each case the product of velocity and effective area.

TABLE 1

RELATIONS OF PRESSURE, VELOCITY, VOLUME AND HORSE POWER

PRESSURE PER SQ. IN. OZ.	VELOCITY OF DRY AIR AT 50 DEGREES FAHR. ESCAPING INTO OUTER SYSTEM THROUGH ANY SHAPED ORIFICE: Feet per min.	Feet per sec.	VOLUME DISCHARGED IN ONE MINUTE THROUGH AN ORIFICE HAVING EFFECTIVE AREA OF ONE SQ. IN. CU. FT.	HORSE POWER REQUIRED TO MOVE GIVEN VOLUME UNDER GIVEN CONDITIONS
1	86.03	5 161.7	35.85	0.00978
2	121.41	7 284.4	50.59	0.02759
3	148.38	8 902.8	61.83	0.05058
4	170.98	10 258.6	71.24	0.07771
5	190.76	11 445.5	79.48	0.1084
6	208.53	12 511.9	86.89	0.1422
7	224.77	13 486.4	93.66	0.1788
8	239.80	14 387.9	99.92	0.2180
9	253.83	15.229.6	105.76	0.2596
10	267.00	16 020.4	111.25	0.3034
11	279.70	16 768.1	116.45	0.3493
12	291.30	17 478.2	121.38	0.3972
13	302.59	18 155.2	126.06	0.4470
14	313.38	18 802.7	130.57	0.4986
15	323.73	19 423.6	134.89	0.5518
16	333.68	20 020.7	139.03	0.6067
17	343.26	20 595.8	143.03	0.6631
18	352.52	21 151.0	146.88	0.7211
19	361.46	21 687.8	150.61	0.7804
20	370.13	22 207.5	154.22	0.8412

6 The theoretical horse power is the product of pressure, velocity and effective area.

7 For refined work, or under conditions of wide variation from the basis of the table, corrections should be made for differences in humidity and temperature.

8 In the ordinary processes of the foundry, where iron or the less

refractory metals are to be reduced, the resistance of the crucible, air, or cupola furnace will roughly range from somewhat above one ounce to a possible but usually unnecessary pressure in excess of 20 ounces per square inch.

9 Up to about 8 ounces the fan blower cannot be excelled for convenience and efficiency. From 8 to 16 ounces the field is fairly divided between the fan and the rotary types, the advantage gradually shifting from the former to the latter as the pressure increases. Above 16 ounces the superiority of the rotary type is manifest, until it in turn encroaches upon the efficient field of the blowing engine at about 5 pounds; a pressure far in excess of the practical requirements of the foundry. The air compressor, as an aid to combustion, is economically useful only in connection with the burning of liquid fuel.

10 The fundamental differences between the fan and the rotary type of blower lie in the manner of creating pressure and in the effect of resistance.

11 In the fan type, velocity is given to the air in its passage from the inlet to the circumference of the revolving wheel. This is transformable into pressure with corresponding density within the enclosing case and connections; the pressure being dependent upon the number of revolutions. In the case of a fan blower at constant speed, the volume and power decrease as the resistance increases. When the outlet is closed, the wheel continues to revolve at the same speed, but without effective delivery, and with minimum power expenditure.

12 In the rotary, or so called "positive" type, air in regularly succeeding volumes is imprisoned by one or more enclosed revolving impellers, and forced forward against the imposed resistance. It is thereby compressed to a density, and given a pressure proportionate to that resistance. This pressure is fundamentally independent of the number of revolutions. The delivery remains practically constant for a given speed as long as discharge is permitted, while the power expenditure increases with the resistance. When the outlet is closed, the power required is at the maximum, and the displacement, though ineffective, is just equal to the slip; up to the limit of power to drive and of strength to endure.

13 The construction and proportions of a prevalent type of cupola fan blower are illustrated in Fig. 1. The casing and wheel are provided with two inlets, which, in ordinary construction, are about one half the diameter of the wheel. The width of such a wheel at its periphery ranges from 5 to 8 per cent of the diameter, the width between side plates at the inlet being approximately one sixth of

the diameter. From 6 to 8 major blades extend from inlet to circumference; between these are one, two or three times as many minor blades of about one half the radial length. All blades are slightly curved backwards at the circumference of the wheel. The cast iron casing is of involute form, its greatest diameter being approximately 1¾ times the diameter of the enclosed wheel.

14 In the volume type, designed for much lower pressures, such as are required in air furnace operation, the peripheral width of the wheel ranges from 20 to 40 per cent of its diameter. The casing is often of steel plate.

15 Refined consideration of blower design is not necessary in a discussion of foundry blower practice, but a knowledge of fundamental principles and empirical relations is essential to a clear understanding of the subject.

16 The manufacturers' rating of the type of blower shown in Fig. 1 is based upon the greatest effective area over which it will maintain the maximum velocity of discharge. As originally established by Sturtevant, this "capacity area" or "square inches of blast" is represented by the empirical formula

$$\text{Capacity area} = \frac{DW}{3} \qquad [5]$$

in which D = diameter of wheel in inches
W = width of wheel at circumference in inches.

17 This formula was derived from the pressure type of fan blower The value of the divisor must necessarily vary with the proportions of the wheel, the number of inlets, the number and curvature of the blades, and the form of the enclosing case. But as a merely arbitrary basis, the formula has been generally accepted for the ready comparison of wheels of substantially the same type.

18 Manifestly the maximum velocity of discharge will create the maximum total pressure. As a factor in the manufacturers' rating this attainable velocity has been accepted as being equal to the circumferential speed of the wheel. This assumption is by no means universally correct.

19 Recent developments in fan construction with very large inlets, numerous shallow blades, and unusual width, show discharge velocities far in excess of the circumferential speed, approximating a theoretical maximum of twice that speed. But successful application of such fans has not yet been made under the resistance obtaining in cupola practice.

20 It is evident that, disregarding the effect of changes in density

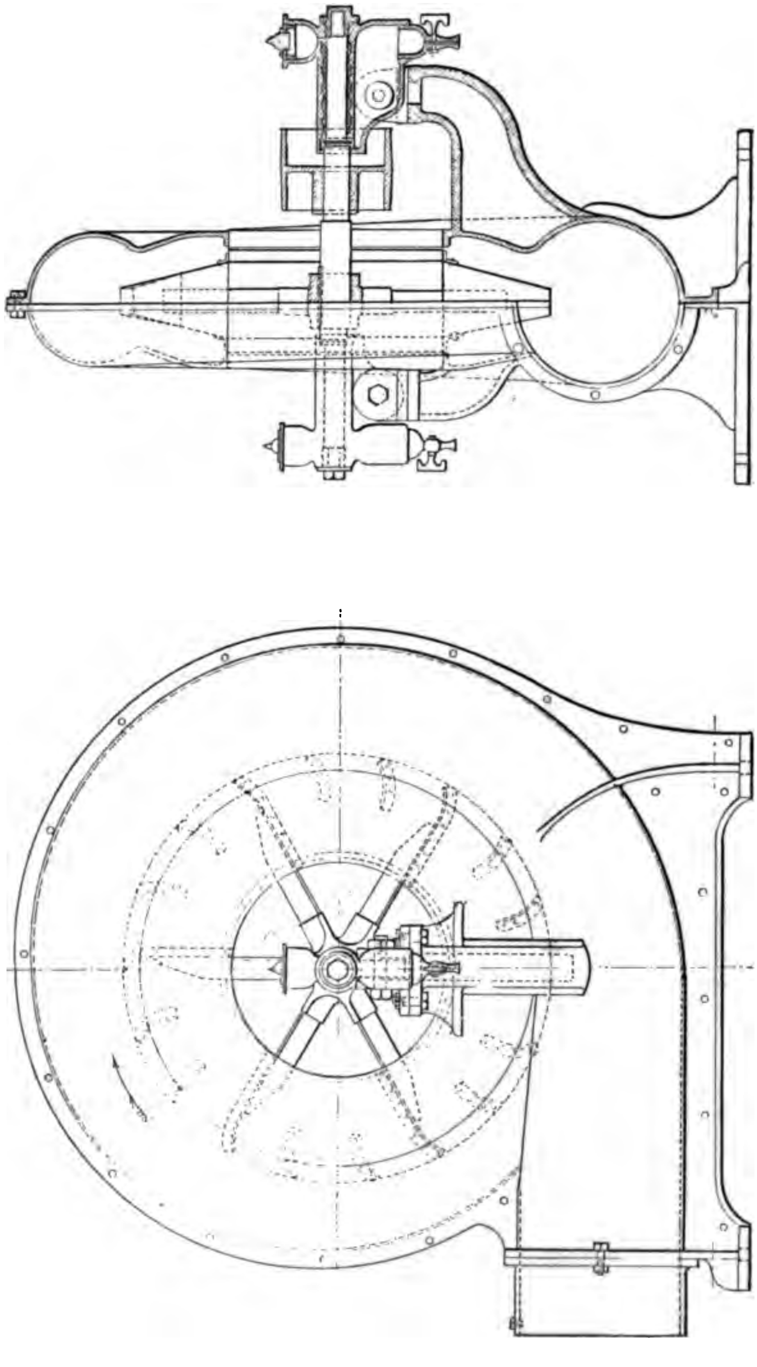

FIG. 1 FAN BLOWER

and temperature, the following relations should hold for a given fan with constant capacity area:

a the volume varies directly as the revolutions,

b the pressure varies directly as the square of the revolutions,

c the power varies directly as the cube of the revolutions.

21 These relations clearly point to the economic desirability of closely proportioning the fan to the work it is to perform. An increase of only 25 per cent in the speed, which may be necessitated by deficiency in the volumetric capacity of a given fan, nearly doubles the power required, and creates a pressure more than 50 per cent in excess of that at normal speed. It is seldom that the sum of fixed charges and operating expense cannot be materially reduced by substituting a larger and more costly fan for one that must be run at unnecessary speed to deliver the required volume.

22 The speed of a fan is usually fixed, and variations occur only in the effective area of discharge. In cupola practice such variation is extensive, and changes often succeed each other with frequency. Hence it is difficult to proportion the fan to secure the most economical average performance. It must have capacity to deliver the required volume under the greatest resistance, toward the end of the heat, but the power provided must be sufficient to drive it during the early part of the heat when there is less resistance, greater delivery and consequently more work to be done.

23 For the ordinary type of fan it has been generally accepted that within the capacity area

a The velocity and pressure are maximum and constant.

b The volume and horse power are proportional to the area.

24 These relations are only approximate, as is evident from Fig. 2. The curves are characteristic of an individual instance in which the fan ran at constant speed while discharging through various outlet areas. All values are relative to the performance at capacity area. Changes in the proportion or the speed of the fan would materially affect these relations, causing them to approach or recede from the conditions expressed in the preceding paragraph, and shifting the point of maximum efficiency.

25 These curves serve to show that

a Maximum efficiency in power and pressure are secured at or near the capacity area.

b The power per unit of volume and the pressure decrease as the discharge area and volume increase.

c With closed outlet the power is approximately one third of that at capacity area.

26 From the preceding it must be manifest that no simple exact basis of calculation can be established for varying fan proportions and conditions. For all practical purposes, however, the manufacturer's basis, although only approximately correct, is sufficiently

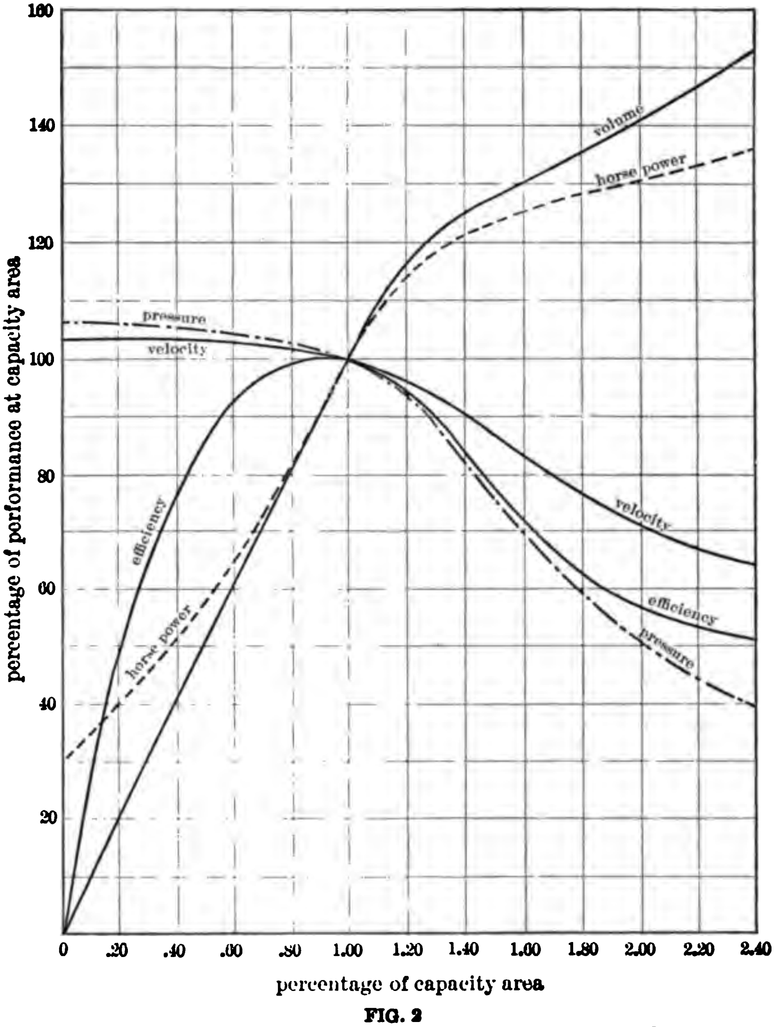

FIG. 2

RELATIVE PERFORMANCE OF A FAN AT CONSTANT SPEED WITH VARIABLE OUTLET AREA

accurate, particularly in cupola practice, where operation at or near the capacity area is essential.

27 Upon this basis Table 2 has been calculated to show the performance at capacity area per inch of peripheral width of typical

diameters of cupola fan blowers. Basic values are taken from Table 1, the air being dry, and of 50 degrees fahr. temperature; the velocity of discharge is taken as equal to the circumferential speed of the wheel, and the power, as double the theoretical. While 50 per cent efficiency is below that which may be attained in good cupola installations, it is always desirable to provide ample surplus above the power required at capacity area. Even a change of 50 degrees from the ordinary inlet temperature makes a difference of about 10 per cent in the power.

TABLE 2

PERFORMANCE OF CUPOLA FAN BLOWERS AT CAPACITY AREA PER INCH OF PERIPHERAL WIDTH

DIAM. OF WHEEL INCHES CAP. AREA SQ. INS.	ITEM	TOTAL PRESSURE IN OUNCES PER SQUARE INCH										
		6	7	8	9	10	11	12	13	14	15	16
18 in. 6 sq. in.	r.p.m.	2660.0	2860.0	3050.0	3230.0	3400.0	3560.0	3710.0	3850.0	3990.0	4120.0	4250.0
	cu. ft.	520.0	560.0	600.0	640.0	670.0	700.0	730.0	760.0	780.0	810.0	830.0
	h.p.	1.7	2.1	2.6	3.1	3.6	4.2	4.8	5.4	6.0	6.6	7.3
24 in. 8 sq. in.	r.p.m.	2000.0	2150.0	2290.0	2420.0	2550.0	2670.0	2780.0	2890.0	2990.0	3090.0	3190.0
	cu. ft.	700.0	750.0	800.0	850.0	890.0	930.0	970.0	1010.0	1040.0	1080.0	1110.0
	h.p.	2.3	2.9	3.5	4.2	4.9	5.6	6.4	7.1	8.0	8.8	9.7
30 in. 10 sq. in.	r.p.m.	1590.0	1720.0	1830.0	1940.0	2040.0	2140.0	2230.0	2310.0	2390.0	2470.0	2550.0
	cu. ft.	870.0	940.0	1000.0	1060.0	1110.0	1160.0	1210.0	1260.0	1310.0	1350.0	1390.0
	h.p.	2.8	3.6	4.4	5.2	6.1	7.0	7.9	8.9	10.0	11.0	12.1
36 in. 12 sq. in.	r.p.m.	1330.0	1430.0	1530.0	1620.0	1700.0	1780.0	1850.0	1930.0	2000.0	2060.0	2120.0
	cu. ft.	1040.0	1120.0	1200.0	1270.0	1340.0	1400.0	1460.0	1510.0	1570.0	1620.0	1670.0
	h.p.	3.4	4.3	5.2	6.2	7.3	8.4	9.5	10.7	11.9	13.2	14.5
42 in. 14 sq. in	r.p.m.	1140.0	1230.0	1310.0	1380.0	1460.0	1530.0	1590.0	1650.0	1710.0	1770.0	1820.0
	cu. ft.	1220.0	1310.0	1400.0	1480.0	1560.0	1630.0	1700.0	1770.0	1830.0	1890.0	1950.0
	h.p.	3.9	5.0	6.1	7.3	8.5	9.8	11.1	12.5	13.9	15.4	17.0
48 in. 16 sq. in.	r.p.m.	1000.0	1070.0	1150.0	1210.0	1270.0	1330.0	1390.0	1450.0	1500.0	1550.0	1590.0
	cu. ft.	1390.0	1500.0	1600.0	1690.0	1780.0	1860.0	1940.0	2020.0	2090.0	2160.0	2230.2
	h.p.	4.5	5.7	7.0	8.3	9.7	11.2	12.7	14.3	15.9	17.7	21.0

28 Characteristic types of single and double impeller rotary blowers are presented in Fig. 3 and 4. Numerous other designs are, or have been, in use.

29 In the type shown in the skeleton cross-section in Fig. 2, the single impeller is made up of three diamond shaped blades extending from a central web. On either side of the web a stationary core fills the space within the inner circumference of the blades, forming in connection with the enclosing case an annular space within which they revolve. The rotor which co-incidentally revolves in the smaller

portion of the casing, successively provides pockets to receive and pass the revolving impeller blades to the suction side of the blower, without allowing the escape of compressed air. The rotor is in effect an idler which calls for no power expenditure other than that required to overcome friction.

30 In the type shown in Fig. 4, both impellers are symmetrical

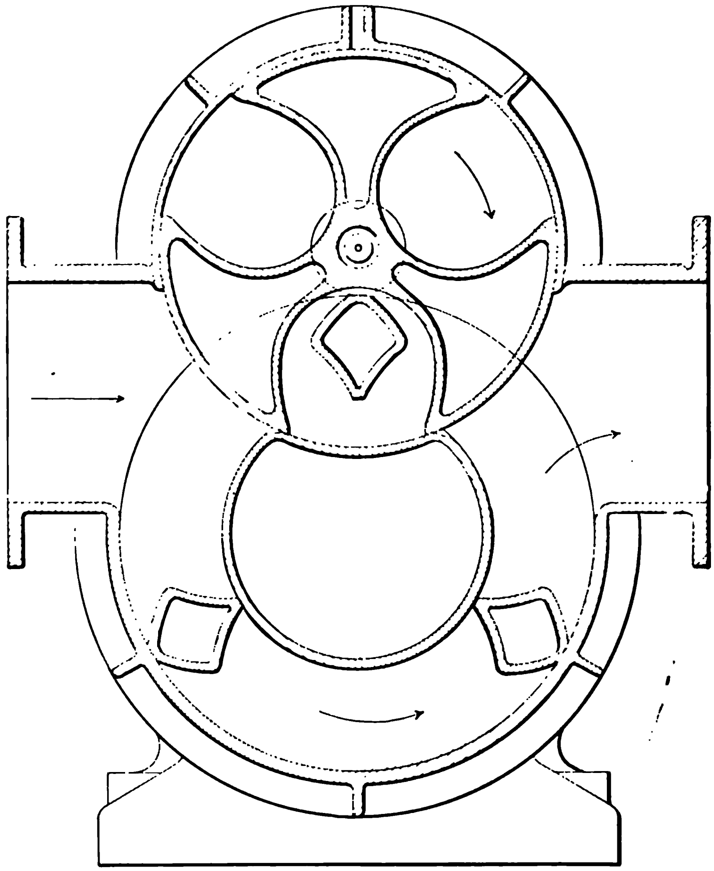

FIG. 3 ROTARY BLOWER
SINGLE IMPELLER, TRIPLE BLADED TYPE

and counterparts of each other. The surfaces are so formed, and the impellers are so located on their respective shafts, as to permit of rotation with uniform clearance, and without metallic contact. Release of air on the discharge side of each impeller is practically coincident with the cut-off of admission on the inlet side.

31 In both types, the air passing through the inlet is imprisoned, and carried forward to the outlet side. Here it meets and mingles with an air of greater density, already compressed by previous action of the impellers. Equalization of pressure instantly results. As a

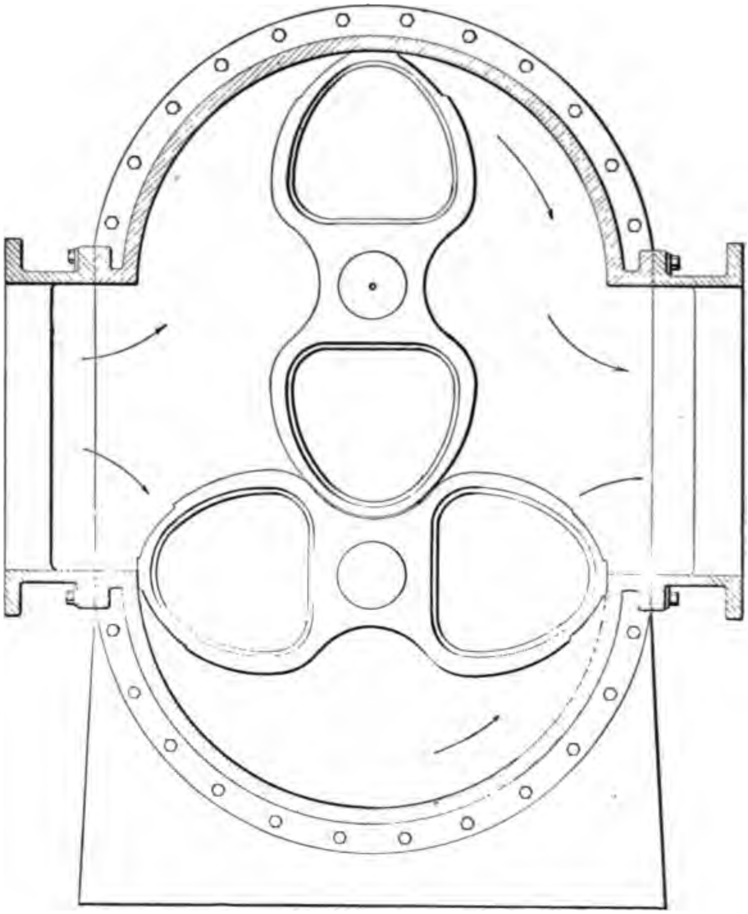

FIG. 4 ROTARY BLOWER ;
DOUBLE IMPELLER TYPE

consequence, there is more or less fluctuation coincident with the revolutions of the blower. The degree of fluctuation depends upon the ratio between the released volume and the total volume under compression, and also upon the extent to which the air has been previously compressed in transit through the blower. This occurs in the case of the single, but not of the double impeller type here illustrated.

32 The theoretical relations which prevail in the case of a rotary blower having a fixed free area of discharge and no slip, are identical with those already specified for the fan type operating within its capacity area, namely; the volume, and consequently the velocity, vary as the number of revolutions, the pressure varies as the square, and the power as the cube of the revolutions. But here the similarity ends, for in the fan the number of revolutions is an essential function of the pressure, while in the rotary blower they are entirely independent. In other words, material change of total pressure with the fan type can only be secured within the capacity area by change in revolutions, while with the rotary type, great range in pressure is attainable, at constant revolutions by merely varying the resistance.

33 Under conditions of constant speed, and variable outlet or resistance, the performance relations of a theoretically perfect rotary blower are as follows, the effect of changes in temperature and density being disregarded:

a The volume is constant.
b The velocity varies inversely as the effective outlet area.
c The pressure varies inversely as the square of the outlet area, hence as the square of the velocity.
d The power varies directly as the pressure.

34 But the mechanical necessity of clearance, and the consequent slip or backward leakage, affect these relations particularly as the conditions depart from the field of maximum efficiency. The slip is theoretically, and in practice, approximately proportional to the square root of the pressure difference between the atmosphere and the imprisoned air, that is, to the velocity which it creates. It therefore results that the volumetric efficiency decreases as the pressure increases.

35 Fig. 5 presents characteristic curves showing relative performance of a single impeller blower of the type illustrated in Fig. 3. The rapid drop in mechanical efficiency at pressures below one-half pound is manifest.

36 The performance of a two impeller type, like Fig. 4, at different speeds and resistances, is illustrated by the curves in Fig. 6. Volumes and horse powers are relative.

37 Under specific conditions of constant speed and resistance, it might be possible to establish the superiority of one type of blower above the other, based primarily upon first cost and operative effi-

ciency. But conditions vary as do blowers, which for commercial reasons are built in stated sizes from which selection must be made. Hence the problem is complicated, and the solution becomes to a considerable degree dependent upon the intangible factor of "adaptability."

38 With no purpose of definition as to advantages or disadvan-

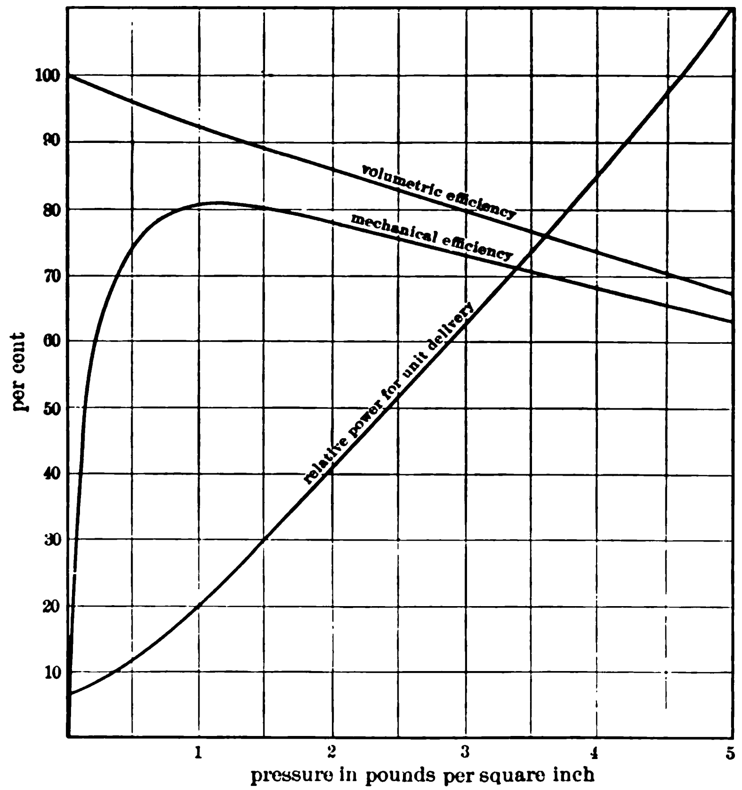

FIG. 5

RELATIVE PERFORMANCE OF A SINGLE IMPELLER ROTARY BLOWER AT CONSTANT SPEED WITH VARIABLE RESISTANCE

tages, the characteristics of the two types operating within practical limits may be thus summarized and contrasted:

39 With a fan blower the maximum pressure is determined by the number of revolutions; with a rotary blower it depends upon existing resistance or the weighting of the relief valve.

40 The volume discharged by a fan blower is dependent upon the outlet area and the corresponding pressure; in the rotary type it is independent of both.

41 The maximum power is required when a fan blower discharges against the least, and when a rotary blower discharges against the greatest resistance.

42 The fan blower automatically increases the created pressure as the opposing resistance becomes greater, until it equals the maxi-

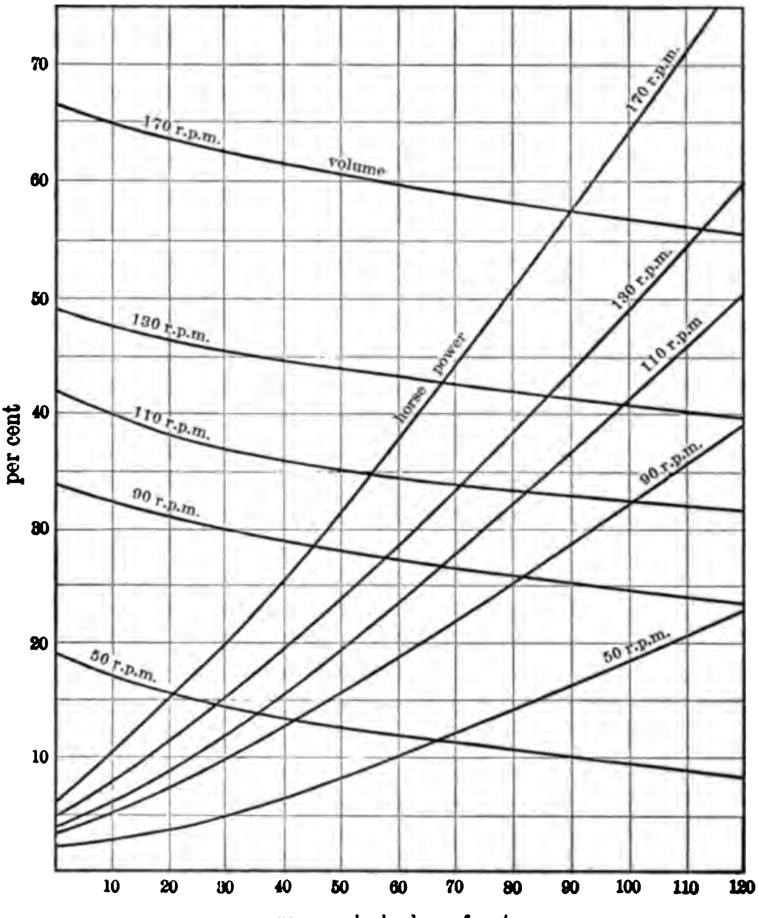

FIG. 6

RELATIVE PERFORMANCE OF A DOUBLE IMPELLER ROTARY BLOWER AT VARIOUS SPEEDS AND PRESSURES

mum pressure capacity of the fan. The volume, although coincidentally decreased, is rendered effective by the greater pressure, while the power is roughly proportional to the effective work. The rotary blower is likewise automatic up to the limit of pressure temporarily established by the resistance of the relief valve, but without material change of volume, and with increase in power. Above the pressure limit set by the valve, air escapes to the atmosphere, and the power expended thereon has no useful effect.

43 The weight and cost of a fan blower are far less, and the speed far higher than in the case of a rotary blower; at low pressures the efficiency of the fan is superior while at the higher pressures necessary in the cupola, the rotary type excels.

44 As the total head or pressure created by a blower represents the sole means of producing movement of the air, whatever portion of this head is consumed in overcoming the frictional resistance of piping and fuel reduces by just so much the amount remaining available for the production of velocity. The greater the ratio between the surface of a pipe and the quantity, and the higher the velocity, the greater is the resistance.

45 Were the outlet in the casing of a fan blower to be made equivalent to the capacity area, the velocity and corresponding friction would be excessive. But in both the fan and rotary types, the area of the outlet is such that the velocity of discharge seldom exceeds 3000 feet per minute. Even this is so great that material saving in power may be secured in a long pipe by making its area considerably in excess of the blower outlet. For instance, the frictional loss in 100 feet of 10 inch pipe with 3000 feet velocity will be practically 1 ounce; while that in a 12 inch pipe, passing about the same volume at 2000 feet velocity, will be approximately $\frac{3}{8}$ ounce.

46 If a certain velocity pressure is required at the point of final delivery, it is manifest that the blower, if in a distant location, must create a total pressure sufficiently in excess to allow for the loss by friction. A drop of a couple of ounces is not uncommon with an ordinary piping system.

47 The actual conditions in a conduit may be determined by a Pitot tube, and calculations of volume made therefrom. The most satisfactory form of instrument appears to be that devised by Mr. D. W. Taylor, and described in his paper before the Society of Naval Architects and Marine Engineers, November 1905. Care must be exercised in the use of any form of pressure gage in order to avoid misleading readings. This is particularly true regarding determination of pressure in the wind-box of a cupola, wherein the direction of air currents is uncertain.

48 The modern cupola furnace is typical of metallurgical progress in which conservation of heat has been secured by massing fuel and metal. As arranged in successive charges with a melting zone of

maximum temperature beneath, the best possible opportunity is presented for the gradual ignition of the fuel and heating of the metals in their downward course.

49 It would at first appear that equal facility was provided for securing complete combustion, and that the quantity of air furnished might closely approximate the chemical requirements. But to secure the best results the volume is reduced in practice considerably below that theoretically required; of necessity incomplete combustion results. The conditions are closely similar to those in the blast furnace.

50 The reason for this condition is to be found in the arrangement of the superimposed charges of fuel and metal with relation to the air supply, which necessitates passing through the lower charges all of the air required for those above. Although perfect combustion with an excess of air is thereby secured in the melting zone, the tendency of excessive dilution is to cool the gaseous mixture to a temperature even below that of the molten iron. Under such conditions less heat is transferred to the upper charges, because of the higher velocity and lower temperature of the gases.

51 The air supply to a cupola is not, therefore, to be determined by the chemical requirements of the entire body of fuel, but by the excess which the lower charges are able to endure without disastrous cooling. The level of the ignition zone, and the completeness of combustion, are necessarily limited by this excess.

52 The introduction of two or more rows of twyers with large aggregate area, has served to distribute the air admission, to reduce the cooling effect in the melting zone, to raise the level of the ignition zone, and to perfect the combustion. But a coincident—and otherwise beneficent—increase in the height of the charging door has still prevented the attainment of complete combustion, although a larger proportion of the heat is utilized.

53 Authoritative chemical analyses of the escaping gases are exceedingly rare, but such as are available show that only about 50 per cent of the carbon combines to form carbon dioxid. The balance escapes as an element of carbon monoxid having less than one-third of the heat value. In other words, only about two-thirds of the possible heat of combustion is utilized. This indicates a shortage of about 25 per cent in the air supply.

54 The intermittent operation of the ordinary cupola is not conducive to the ready utilization of the waste heat by external means, as is possible in the case of the blast furnace. Further economy is therefore to be sought within the cupola itself, and in the application

of the blower thereto, presumably along the lines in which improvement has already been made.

55 · The air supply to a cupola is usually expressed in cubic feet per net ton of iron melted. The amount necessarily varies with the melting ratio, the density of the charges, and the incidental leakage. Fair average practice is represented by the following:

Pounds iron per pounds coke	Cubic feet of air per ton of iron
6	33 000
7	31 000
8	29 000
9	27 000
10	25 000

It is customary to provide blower capacity on a basis of 30 000 cubic feet, which corresponds to 75 or 80 per cent of the chemical requirements with average coke, and a melting ratio of 7.5 to 1. This is evidently ample for any higher ratio.

56 Obviously, neither the rate of combustion nor the rate of melting, can remain constant under the varying conditions within the cupola. In fact it is not fundamentally necessary that they should. But the blower is usually run at constant speed, and delivers uniform volume except as reduced by resistance.

57 As a rule this reduction, which occurs only in the case of the fan, is relatively slight, for the volume (of which the velocity is a function) varies as the square root of the pressure. Hence, for instance, a 20 per cent drop in pressure entails only about 10 per cent loss in volume. Fairly constant pressure with a more regular, though not uniform volume, is therefore to be expected in fan blower cupola practice, as well as a moderate melting rate due to delayed combustion, resulting from reduction in air supply coincident with increase in resistance.

58 As ordinarily installed the resistance of a cupola will never exceed the pressure which a rotary blower can create if sufficient power is supplied. If no relief valve is provided, or it is set high enough to prevent escape, all air must be discharged through the cupola, hence the volume will be practically constant. As the pressure equals the resistance, considerable variation is to be expected during the heat, while, owing to the maintenance of uniform air supply, a more rapid rate of melting may be possible than with the fan.

59 These expectations are usually fulfilled in practice, although the contrast lessens as the proportioning of the blower to the cupola approaches the ideal. So far as the blower is concerned, its actual volumetric output, relatively to the cupola requirements, is the

determining factor in the melting rate. Fundamentally, the resistance regulates the volume in the case of the fan, while the volume regulates the resistance in the case of the rotary blower. Otherwise expressed, the fan type adjusts itself to the conditions, decreases the power and volume, and somewhat reduces the melting rate, while the rotary type in a resistless way continues to force through the cupola the prescribed volume regardless of immediate requirements or power expenditure, and usually maintains the maximum hourly output.

60 For the purpose of illustration, extreme contrasts between the operation of a fan blower and a rotary blower are graphically presented in Fig. 7. These curves are based on tests reported by Mr. H. E. Field at the December 1904 meeting of the Pittsburg Foundrymen's Association. The blowers, a No. 10 Sturtevant fan and a 33 cubic foot Connersville rotary, were installed for alternate use in connection with a 54-inch lining cupola. So far as possible the charges were alike in weight and character in both cases. The scrap was heavy, and of such shape as to pack closely. These tests will be made the basis for some pertinent comparisons.

61 Here are practically identical conditions of cupola and contents, but great contrasts in operation which show the effect of variation in air volume and pressure. With the fan blower the pressure was comparatively constant, the variation being between 12½ and 14½ ounces in the wind box with an average of 13.6. The net power ranged from 25 to 38.5 horse power, with an average of 31.2. The pressure with the rotary blower varied through the extreme range between 10½ and 25 ounces, while the average stood at 20.63. The variation in horse power was between 19 and 45, the average being 35.8.

62 With the fan 28.84 tons were melted in 3.77 hours, at the rate of 7.65 tons per hour, while with the rotary blower 2.82 hours were required to melt 31.5 tons, at an hourly rate of 10.6 tons, an increase of nearly 40 per cent in output. This reduces to a net input of 4.09 horse power per ton melted per hour with the fan, and 2.98 horse power with the rotary blower; an apparent advantage of 27 per cent in favor of the rotary.

63 By far the larger quantity of air was discharged by the rotary blower, the rate of melting being closely proportional to the volume, as may be shown by a careful analysis of the tests. The rate is low for the size of the cupola, extremely so in the case of the fan, and is in part at least the result of excessive resistance presented by large pieces of scrap.

64 The results shown by these tests emphasize the possible effect of changes in the relation of the blowers to the cupola. Had the rotary blower been of smaller capacity such excessive pressures would not have been necessary to force the constant volume through the cupola; the power would have been decreased, and the duration of the heat prolonged, with probable decrease in the horse power hours per ton. Had the fan been run at higher, but not excessive speed to permit of passing a larger volume, which it was fully capable of de-

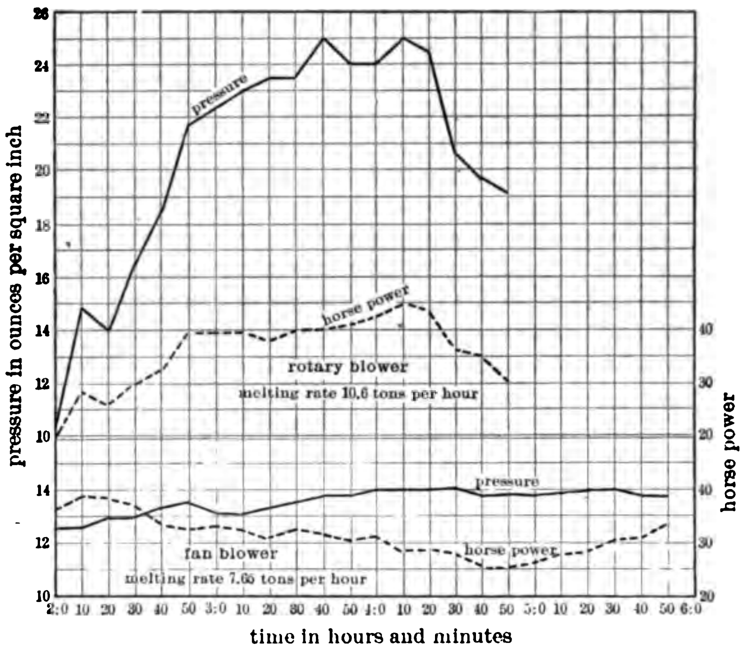

FIG. 7 PERFORMANCE OF FAN AND ROTARY BLOWER ON A 54-INCH CUPOLA

livering, the horse power would have increased, the time decreased and the power per ton per hour would certainly have more closely approached that required by the rotary blower.

65 A subsequent unofficial, but credible, test made upon the same cupola equipped with a No. 8 Sturtevant fan, presents an instructive contrast. The conditions were identical with those in the previous tests, except that a small amount of very light scrap was charged. The results showed 9.41 tons melted per hour, with an average pressure of 12.5 ounces and a power expenditure per ton per hour less than 80 per cent of that required with the No. 10 fan.

66 The preceding renders manifest the difficulties in the way of exactly proportioning blowers to the somewhat unknown conditions of their work, and likewise the futility of attempting to base comparisons of ultimate efficiency upon such limited experiments. In contrast thereto, it can be shown that a No. 10 Sturtevant fan, upon a 60-inch cupola, regularly melted 13.8 tons per hour, with an expenditure of 2.6 horse power per ton, and a No. 8, upon a 42½ inch, required only 2.9 horse power per ton upon a total output of 6.46 tons per hour. And likewise that rotary blowers of identical size and quality have shown results both inferior and superior to those here reported.

67 The higher speed of melting, which, because of its ability to overcome excessive resistances, may be maintained by the rotary blower, is universally recognized, as is also the increased time thus rendered available for molding before the first iron is tapped. But the greater pressure incident to the higher rate is much more severe in its cutting effect upon the lining, while the value of the time gained for molding depends upon individual foundry conditions. The superior mechanical efficiency of the rotary type is, to a greater or less degree, offset by much lower first cost and fixed charges on the fan. The necessity of providing power capacity greatly in excess of the average in the case of the rotary blower is not to be overlooked. Neither is it to be forgotten that the brief duration of the heat reduces the difference in annual expenditure for power to a relatively unimportant item. For instance, under the exceptional conditions in the tests shown in Fig. 7, the daily difference in electrical horse power hours input was only 20.3. On a basis of 10 hours per day this equals only 2 horse power continuously exerted.

68 Theoretically, for otherwise constant conditions, the following relations hold for cupolas and melting rates within the range of practical operation;

- *a* The melting rate with constant volume varies directly as the square of the diameter, that is, as the cross sectional area of the cupola, and directly as the volume, as the square root of the pressure, and as the cube root of the power for a given cupola.
- *b* The volume varies inversely as the square of the cupola diameter for a given melting rate, and directly as the melting rate for any cupola.
- *c* The pressure with a given cupola varies directly as the square of the volume, that is, as the square of the melting rate, and as the depth of the charges for a given melting rate.
- *d* The power with a given cupola varies directly as the cube

of the melting rate, and as the cube of the square root of the pressure, and directly as the pressure for a given melting rate and any cupola, i. e., inversely as the fourth power of the diameter for a given melting rate.

e The power per ton per hour (the operating efficiency) for a given cupola varies directly as the square of the melting rate, that is, as the pressure; and for a given melting rate directly as the rate for a given pressure, directly as the pressure and inversely as the fourth power of the diameter.

f The duration of the heat for a total output for a given cupola varies inversely as the square root of the pressure.

69 These relations might well be the source of numerous formulae for practical use were it possible to establish accurate coefficients. But the great variety in cupolas, twyerage proportions, and character of fuel and iron, to say nothing of the difference in charging practice in different foundries, or even the variety in the same foundry, is bewildering and discouraging. Maximum efficiency in a given case can only be assured after direct experiment. But something short of the maximum is usually accepted in ignorance of the ultimate possibilities. But even though subject to some variation under working conditions, the preceding relations point clearly to the factors that make for maximum efficiency. It is obvious that pressure and melting rates should be as low, and cupola diameters as great as practical considerations will allow.

70 High pressure is a relic of small twyer area, in a single course, of coal as fuel, of false economy in buying a fan blower so small as to require excessive speed to deliver the required volume, or a rotary blower so proportioned to the cupola that high pressure is inevitable, and above all, of forcing the cupola beyond the economical limit. It is no longer considered creditable to secure the largest possible output from a given cupola; it is better practice to use a larger cupola for the same output. The tendency is distinctly in the line of more moderation, both because of higher ultimate operating efficiency, and the improved quality of the castings.

71 Fig. 8 and 9 clearly indicate the economy of such a course. It is to be noted that although the curve of maximum output in Fig. 8 is freely drawn through points representing good current practice, it conforms closely to the relations expressed above, i. e., that the melting rate varies directly as the square of the diameter. Wide variations are to be expected in individual cases. The maximum pressures capable of maintaining the corresponding melting

rates under proper conditions vary with the diameter and the height of the cupola, as well as with the proportions of the charges. Other melting rates are plotted in proportion to the square roots of lesser pressures for corresponding cupola diameters. It is, however, because of the great variety in conditions that the values indicated by this or any other set of curves are purely relative and cannot be made directly applicable to cupola practice in general.

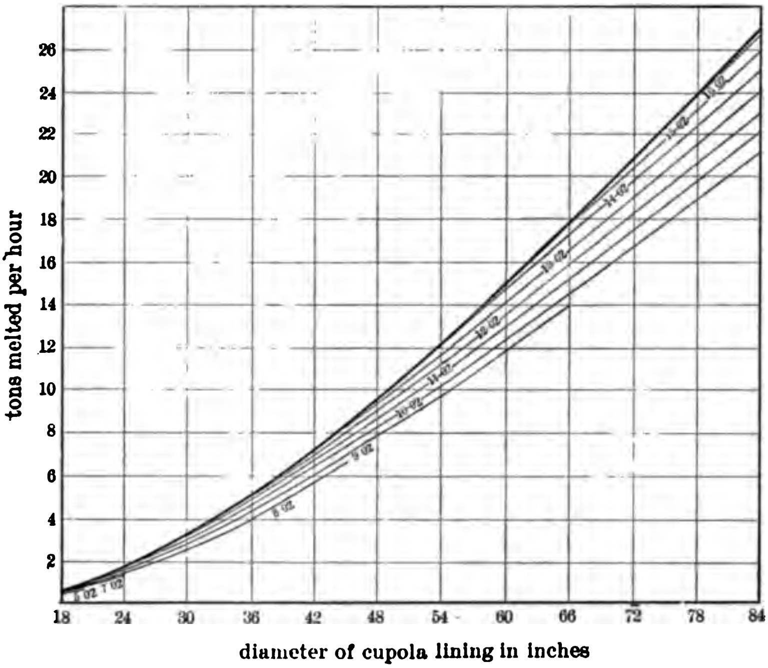

FIG. 8 CUPOLA PERFORMANCE AT DIFFERENT PRESSURES

72 The power economy of low pressures and melting rates is clearly shown by Fig. 9. The lines of unit expenditure have been arbitrarily fixed in the middle field of good practice.

73 The actual melting range of a cupola is ordinarily between 0.6 and 0.75 ton per hour per square foot of cross section. The limits of air supply per minute per square foot are roughly 2500 and 4000 cubic feet, with the mean as representative of fair practice. The possible power required varies even more widely, ranging from 1.5 to 3.75 horse power per square foot, corresponding respectively to 2.5 and 5 horse power per ton per hour for the melting rates specified above.

74 Current practice can only be expressed between limits as in the case of Table 3. Therein is given the ordinary range of the different variables for stated cupola diameters. The specified pressures prevail most extensively in recent installations. In so far as it is possible to determine the melting rate and the necessary pressure therefor, the power may be roughly calculated, from the theoretical requirement of 0.27 horse power to deliver 1000 cubic feet per minute at one ounce pressure. The power increases directly

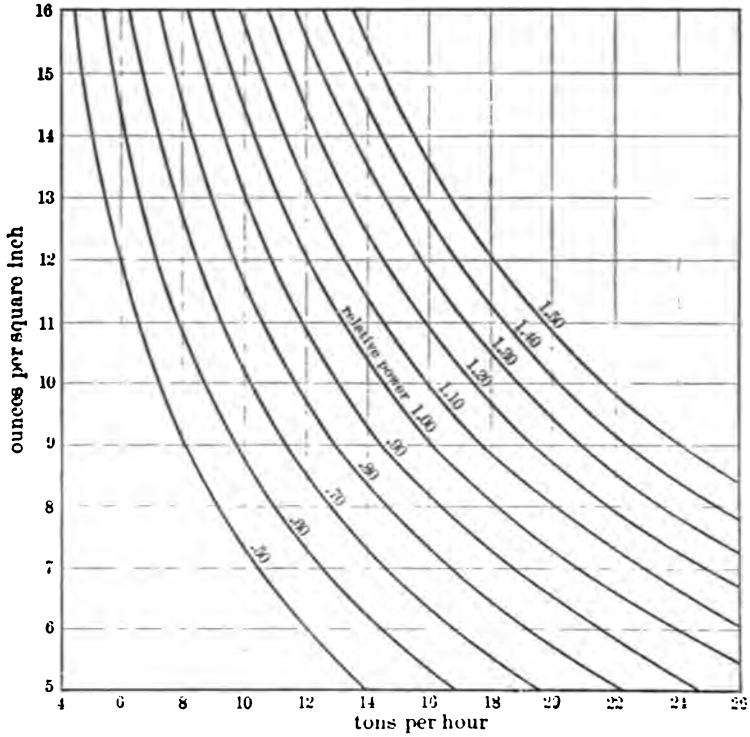

FIG. 9 ROTATIVE POWER FOR DIFFERENT PRESSURES AND MELTING RATES

with the pressure, and is practically dependent upon the efficiency of the blower. This will range from 50 to nearly 70 per cent in a good fan installation, and up to a possible maximum of 90 per cent with a first class rotary blower equipment. The drop in pressure due to an extended system of piping must not be neglected in such calculations.

75 The trend toward lower pressures in the cupola is reflected in current air furnace practice. The high pressure fan blower with

small volumetric capacity has been superseded by the volume fan having ample capacity at much lower pressure.

76 Both volume and pressure are dependent upon the quality of the coal and the rate of combustion. The deep fire lends itself to complete utilization of the air supply, with minimum excess and maximum temperature. Both under and over grate supply pipes should be of ample size to avoid excessive loss by friction, and the

TABLE 3

RANGE OF PERFORMANCE OF CUPOLA BLOWERS

DIAMETER INSIDE LINING. IN.	CAPACITY PER HOUR TONS	PRESSURE PER SQ. IN. OZ.	VOLUME OF AIR PER MIN. CU. FT.	HORSE POWER
18	0.25– 0.5	5– 7	150– 300	0.5– 1.5
24	1.00– 1.5	7– 9	600– 900	2.0– 6.0
30	2.00– 3.5	8–11	1 200– 2 000	5.0– 15.0
36	4.00– 5.0	8–12	2 200– 2 800	10.0– 23.0
42	5.00– 7.0	8–13	2 700– 3 700	12.0– 32.0
48	8.00–10.0	8–13	4 000– 5 000	18.0– 45.0
54	9.00–12.0	9–14	4 500– 6 000	22.0– 60.0
60	12.00–15.0	9–14	6 000– 7 500	30.0– 75.0
66	14.00–18.0	9–15	7 000– 9 000	35.0– 90.0
72	17.00–21.0	10–15	8 500–10 500	45.0–110.0
78	19.00–24.0	10–16	9 500–12 000	52.0–130.0
84	21.00–27.0	10–16	10 500–13 500	60.0–150.0

pressure should be the lowest which, with a properly proportioned blower, will pass the required volume. This pressure need not exceed 2½ ounces per square inch, and under good conditions should be considerably less. The volume delivered beneath the fire may be kept well down toward the theoretical requirements, not exceeding 200 to 225 cubic feet per pound of coal.

77 In the crucible furnace still lower pressures prevail but the air supply is not as effectively utilized.

78 Flexibility in the application and operation of a blower is sufficient to permit of approximation in its size. Unfortunately its size number conveys no idea of its capacity, although rotary blowers are secondarily classified by volumetric displacement. The manufacturer's recommendation, checked by the purchaser's experience, must generally serve as the simplest rule of selection.

DISCUSSION

PROF. A. L. WILLISTON Referring to the curves shown in Fig. 2, I would like to ask the author of the paper if he will state what size and character of a fan these curves are intended to cover, and the corresponding range of pressures and velocities. In the absence of such information, some of us might attempt to apply the conclusions drawn from them to cases so far different from those prevailing in the tests on which these curves are based, as to run the risk of being greatly misled.

2 In attempting myself to draw curves of this sort from different fan experiments, I have found that the curves differ radically according to the different sizes and character of the fans and the conditions under which they are used, and that the very greatest care is necessary whenever the comparison is made between the performances of two different fans, in order to be sure that similarity of conditions is sufficient to warrant the comparison. If the author of the paper, therefore, can add some definite data on this subject he will make his paper of still more value to the members of the Society.

DR. SANFORD A. MOSS In the mathematical introduction with which Mr. Snow prefaces his paper, Table 1 gives computations from an approximate formula which are carried to a much greater number of significant figures than is warranted. The formula 4, which Mr. Snow gives, is the correct formula for very small pressure differences. It assumes an incompressible fluid. This formula is practically correct for pressures up to two ounces per square inch. For greater pressures, a correction must be made to allow for the fact that the density of the fluid changes during expansion. This subject was fully discussed in the American Machinist of September 20 and 27, 1906.

2 The formula which Mr. Snow uses is exactly equivalent to formula 11 of case 5. The proper formula for pressures above two ounces is formula 7 or 9 of case 4. For instance, for the pressure of 20 ounces per square inch, the velocity should be 376 feet per second instead of 370, a difference of nearly 2 per cent. This difference is, of course, not significant for ordinary work and the figures given by Mr. Snow are a close approximation. However, it is not proper under the circumstances to carry the figures to the number of decimal places given.

3 For the higher pressures given in Mr. Snow's table, from six to 20 ounces, an almost exact value of velocity can be obtained by multiplying the quantity within the radical of formula 4 by the expres-

sion $\left(1 + \frac{x}{2k}\right)$ where k is the ratio of specific heats of air and is such that $\frac{1}{k} = 0.711$ and x is equal to $\frac{p}{235 + p}$, using Mr. Snow's notation, where p is the pressure in ounces above atmosphere. For pressures above 20 ounces, the exact formula must be used, as discussed in the references previously cited. When computed by the correct formula, the velocities given by Mr. Snow would have the following values:

Pressure oz. per sq. in.	Velocity ft. per sec.
3	148.9
4	171.7
5	191.6
6	209.7
7	226.2
8	241.5
9	255.6
10	269.2
11	282.0
12	294.7
13	307.0
14	316.7
15	327.5
16	337.5
17	348.0
18	357.5
19	367.0
20	376.0

4 The other columns of the table have slight errors in a similar way. The first few figures given by Mr. Snow are, in all cases, practically correct, the only criticism being that the final figures are not warranted, and give a deceptive idea of their accuracy. A similar remark can be made of the constant 1 746 659 of formula 4. The circumstances do not warrant that this constant should be given to a greater degree of accuracy than 1 750 000.

MESSRS. H. DE B. PARSONS AND DAVID C. JOHNSON Recently it was necessary to work out a fan problem, and sufficient data could not be obtained from the pamphlets and catalogues issued by the fan companies to calculate the size of fan needed under the given conditions. The writers therefore collected from many sources available information regarding the subject, and worked out the following simple formulae and curves, which, it is believed, will enable one to answer most questions which might arise regarding the capacity, speed, horse power, etc., of blowers and disk fans intended for ordinary use.

2 The formulae are to be used for calculating the size and horse power of fans, and are not to be used for designing and calculating the dimensions of the various parts.

3 The formulae are not original, nor is it claimed that they would be accurate under all conditions, although they have been checked with many fans in actual operation, and in all of these cases have given close results. The formulae for the blower type gives closer results than those for the disc type.

4 In the case of disc fans it is very hard to get formulae that will cover all cases, as a slight difference in setting or arrangement will materially affect the result.

Fan Wheel with Peripheral Discharge

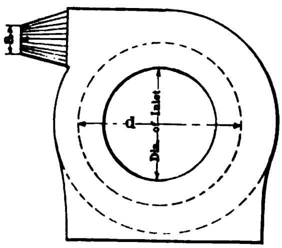

FIG. 1 PERIPHERAL DISCHARGE FAN

5 Calculations for capacity, revolutions and brake horse power:

Q = air discharged in cubic feet per minute.
d = diameter of wheel in feet.
w = width of wheel at tip of blades in feet.
R = revolutions per minute.
V = peripheral velocity of wheel in feet per minute.
v' = theoretical velocity of air in feet per minute.
v = actual velocity of air in feet per minute.
D = density of air in pounds per cubic foot.
B = brake horse power to drive wheel.
a = effective area of discharge or "blast area" in square feet.
h = head of air in feet.
G = acceleration per minute due to gravity = g 32.2 (in feet per second) $\overline{60}^2$ = 11 577 600 feet.
p = pressure of air in pounds per square foot.
K = constant for different temperatures.

6 The above theoretical air velocity curve was obtained from the formulae

$$v' = \sqrt{2\,Gh} = \sqrt{2\,G\frac{p}{D}}$$

D being density of dry air at 50 degrees fahr. = 0.0778 pounds.

7 The peripheral velocity of wheel and actual velocity of discharge curves were calculated from the following formulae obtained by experiment.

$$V = 1.17\,v' \text{ and } v = 0.43\,v'$$

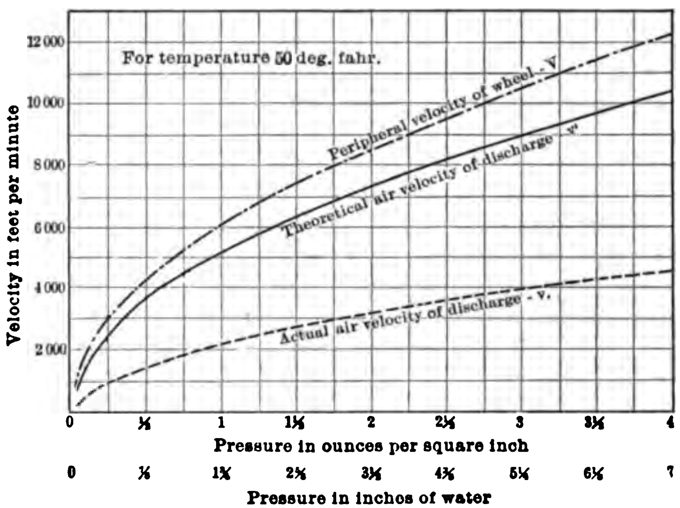

FIG. 2 VELOCITY CURVES

8 The above curves are for dry air at 50 degrees fahr. The velocities vary as the square root of the reciprocal of the densities. At any temperature fahr., the velocities = K times velocity at 50 degrees fahr. Therefore use corrected velocities corresponding to the temperature.

VALUES OF K FOR VARYING TEMPERATURES

Degrees fahrenheit		K	Degrees fahrenheit		K	Degrees fahrenheit		K
30	=	0.98	200	=	1.14	400	=	1.30
50	=	1.00	250	=	1.18	450	=	1.34
100	=	1.05	300	=	1.22	500	=	1.37
150	=	1.09	350	=	1.26	550	=	1.41

9 Usual maximum for V = 6600 feet per minimum, but should not exceed 7200 feet per minimum.

10 Width of blades at tip is usually made about $0.4 \times d$. Width of blades at widest part is made about $0.5 \times d$. When a small volume of air, discharged at high pressure, is desired, the width is less. When a large volume of air, discharge at low pressure, is desired, the width is greater.

11 The last two sentences are true when d or R is fixed, and V or discharge pressure is known.

$$a = \frac{Q}{V} \qquad Q = a \times V$$

$$R = \frac{V}{\pi d}$$

12 By experiment, approximately $a = w\,d \div 3$. Therefore, $a = 0.4d^2 \div 3$, from which d can be found

$$d = \sqrt{7.5\,a} = 2.74\sqrt{a}$$

13 Inlet area in square feet

$$= 0.00054\,Q \div \sqrt{\text{water pressure in inches}}.$$

but should not exceed 40 per cent of disk area of side of wheel.

14 Outlet area in square feet = constant $\times$ inlet area.

For free discharge, the constant varies from 1.0 to 1.25.

For restricted discharge, as into ducts, the fan should be calculated for a pressure equal to that at outlet plus friction.

15 Theoretical brake horse power to drive fan wheel

$$= \frac{Q \times D \times v'^2}{550 \times 2G}$$

B = theoretical horse power times 2. The efficiency being taken at 50 per cent.

DISK FAN

16 Calculations for capacity, revolutions and brake horse power:

Q = air discharged in cubic feet per minute, for "free discharge."

d = diameter of wheel in feet.

R = revolutions per minute.

V = peripheral velocity of wheel in feet per minute.

v' = theoretical velocity of air in feet per minute.

v = actual velocity of air in feet per minute.

D = density of air in pounds per cubic foot.

B = brake horse power to drive wheel.

a = effective area of discharge in square feet.

a = non-effective area of discharge in square feet.

A = disk area of wheel in square feet.
G = acceleration per minute due to gravity $= g$ (in feet per second) $\overline{60}^2 = 11\ 577\ 600$.
C = constant for brake horse power formulae $= 106$.
V should not exceed about 8500 feet per minute.

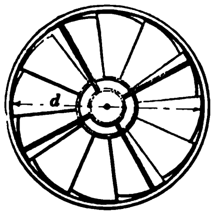

FIG. 3 DISK FAN

17 For restricted discharge or suction, Q becomes less because "slip" becomes greater. Approximately $Q = Av_1$ where $v_1 = v' - v_p$, in in which v_p is 40 per cent of the theoretical velocity due to the difference in pressure on opposite sides of the fan, due to the restriction. B is the same as for "free discharge."

$$A = a + a'$$
$$a = 0.8\ A$$
$$a' = 0.2\ A$$
$$V = \pi\, d\, R$$
$$R = V \div \pi\, d$$
$$v' = \text{pitch ratio} \times V \times \text{per cent slip} = 0.65 \times V \times 0.75$$
$$v = 0.8\ v'$$
$$v' = 1.25\ v$$
$$v = 0.39\ V$$
$$Q = Av = av' = 0.8\ Av'$$

18 The following approximate formulae, evolved by the writers have given good results:

$$B = \frac{Q \times D \times \overline{V}^{\frac{3}{2}}}{33\ 000 \times 2\,G} \times C \text{ in which } C = 106$$

19 For facility in using the above formula the following curve is given which gives the value of $\frac{\overline{velocity}^{\frac{3}{2}}}{2\,G}$ for corresponding values of velocities in feet per minute.

Mr. E. N. Trump We have found the Venturi meter a very satisfactory means for measuring air. We made a series of tests to determine the efficiency of some of the positive blowers, and this meter gave measurements within less than 2 per cent error. I would say, also, that we have made tests at atmospheric pressure and as high as 250 pounds to the square inch, both meters being on the same pipe, and when we made allowance for the difference in temperature and pressure we found the volumes to compare very well.

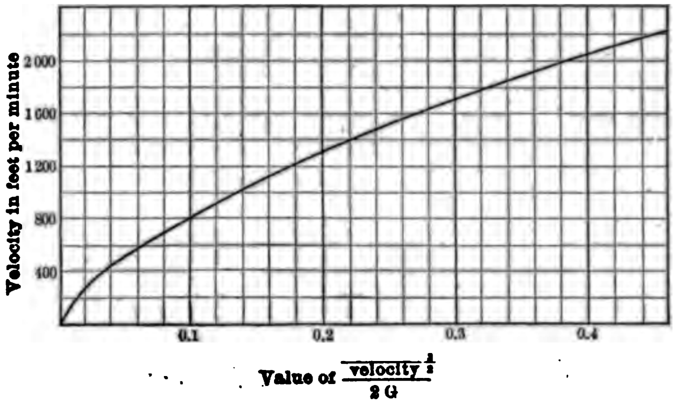

FIG. 4 CURVE GIVING THE VALUE OF $\frac{velocity^2}{2G}$ FOR CORRESPONDING VALUES OF VELOCITIES IN FEET PER MINUTE

Mr. H. M. Lane In this paper some of the figures are in ounces, some are in inches of water and others are in pounds. The tables would prove of more assistance to engineers if the values were stated in terms of some one unit.

Mr. T. S. Bailey While it is true that the very complete series of tests undertaken by Mr. D. W. Tailor related to low pressure blowers only, his methods have been adopted by the Navy Department, and they are exceedingly valuable.

Messrs. J. R. Fortune and H. S. Wells[1] The blowing equipment attached to our cupola, consisted originally of a No. 8 Sturtevant pressure blower which, as Mr. Snow has pointed out, varies its air delivery inversely with the resistance. In order to maintain a positive delivery of air, and thus increase the melting speed, it was decided to install a Sturtevant No. 11 high pressure blower which,

[1] The Murphy Iron Works, Detroit, Mich.

while somewhat larger than is required at the present time, would be adequate for our contemplated new foundry, which will be equipped with 66-inch cupolas. Fig. 1 gives the internal dimensions of the present cupola.

2 The maximum melting rate, from iron down to blast off, with the old blower, was 8½ tons per hour.

3 Fig. 2 is a diagram of the blower revolutions, blast pressure and boiler pressure observed during the first heat with the new blower.

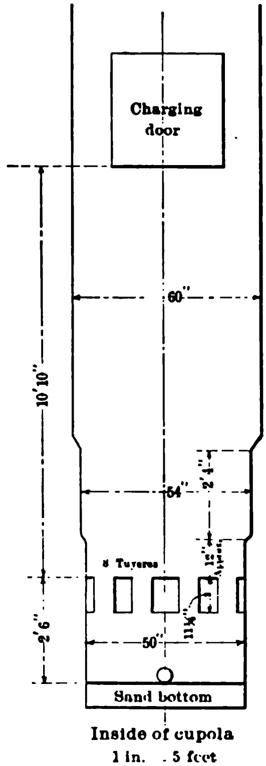

FIG. 1 SHOWING INTERNAL DIMENSIONS OF CUPOLA

At the right of the pressure diagram is a diagram of the cupola and the weights of charges of iron and coke. Table 1 contains the data secured during the trial. The proportion of coke to iron was kept the same as with the old blower and the cupola was unaltered.

TABLE 1

Total iron melted, tons	22.7
Melting rate (blast on to blast off), tons per hour	8.79
Melting rate (iron down to blast off), tons per hour	9.45

Time before iron comes after blast is on, minutes	11
Iron melted per minute per square foot cupola area, based on iron down to blast off (54 inches diameter), pounds	19.81
Iron melted per minute per square foot cupola area, based on iron down to blast off (50 inches diameter), pounds	23.11
One pound coke melts how many pounds iron (including bed)	7.54
Blast pressure, ounces	11.60
Cupola area is how many times twyers area (small end):	
At 54 inches diameter cupola	*9.02
At 50 inches diameter cupola	7.96
Bottom of melting zone above top of twyers, inches	12–18
Weight of iron layer is how many times weight of coke layer	10
Time between starting fire and starting blast, hours and minutes	2:30

* Taken before enlargement of twyers.

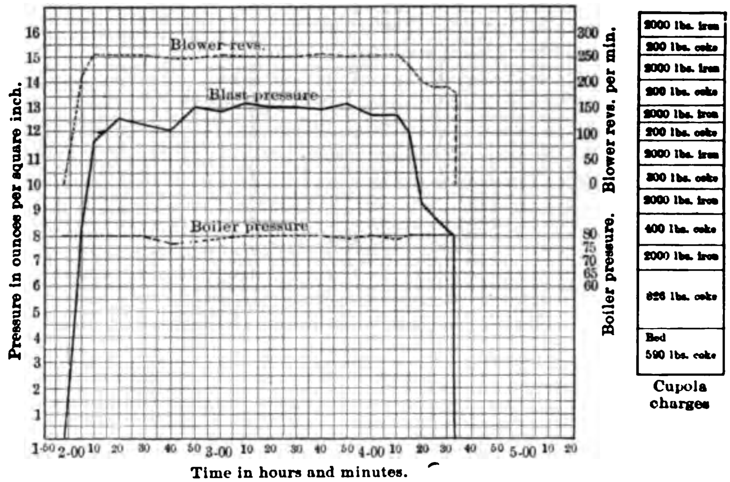

FIG. 2 CUPOLA TEST, STURTEVANT No. 11 HIGH PRESSURE BLOWER

4 The results of tests 2 and 3, which were made after enlarging the twyer openings are given in Table 2 and Table 3; this change being made in the cupola to get in a greater amount of air without increasing the blast pressure.

TABLE 2

Total iron melted, tons	24
Melting rate (blast on to blast off), tons per hour	8.24
Melting rate (iron down to blast off), tons per hour	8.88
Time before iron comes after blast is on, minutes	13
Iron melted per minute per square foot cupola area, based on iron down to blast off (54 inches diameter), pounds	18.61
Iron melted per minute per square foot cupola area, based on iron down to blast off (50 inches diameter), pounds	21.71

One pound coke melts how many pounds iron (including bed)	7.40
Blast pressure, ounces	10.63
Cupola area is how many times twyer area (small end):	
At 54 inches diameter cupola	*5.98
At 50 inches diameter cupola	5.13
Bottom of melting zone above top of twyer, inches	10–12
Weight of iron layer is how many times weight of coke layer	10
Time between starting fire and starting blast, hours and minutes	2:30

* Bed too low.

TABLE 3

Total iron melted, tons	22.15
Melting rate (blast on to blast off), tons per hour	8.20
Melting rate (iron down to blast off), tons per hour	8.86
Time before iron comes after blast is on, minutes	12
Iron melted per minute per square foot cupola area, based on iron down to blast off (54 inches diameter), pounds	18.55
Iron melted per minute per square foot cupola area, based on iron down to blast off (50 inches diameter), pounds	21.64
One pound coke melts how many pounds iron (including bed)	7.28
Blast pressure, ounces	10.00
Cupola area is how many times twyer area (small end):	
At 54 inches diameter cupola	*5.98
At 50 inches diameter cupola	5.13
Bottom of melting zone above top of twyer, inches	10–02
Weight of iron layer is how many times weight of coke layer	10
Time between starting fire and starting blast, hours and minutes	2:30

* Bed too low.

5 Table 4 gives the particulars of a heat which was run after the coke bed had been increased.

TABLE 4

Total iron melted, tons	24.25
Melting rate (blast on to blast off), tons per hour	8.50
Melting rate (iron down to blast off), tons per hour	9.15
Time before iron comes after blast is on, minutes	12
Iron melted per minute per square foot cupola area, based on iron down to blast off (54 inches diameter), pounds	19.17
Iron melted per minute per square foot cupola area, based on iron down to blast off (50 inches diameter), pounds	22.77
One pound coke melts how many pounds iron (including bed)	8.58
Blast pressure, ounces	9.47
Cupola area is how many times twyer area (small end)	
At 54 inches diameter cupola	*5.98
At 50 inches diameter cupola	5.13
Bottom of melting zone above top of twyer, inches	12–14
Weight of iron layer is how many times weight of coke layer	13.33
Time between starting fire and starting blast, hours and minutes	2:30

*Coke charges decreased on account of iron being too hot.

6 It will be noted that while the melting speed was greater than for tests 2 and 3, it was below that of test 1. Upon decreasing the blast pressure, and *at the same time decreasing the amount of coke*, the melting speed was brought up to 9.15 tons per hour, tests 5, 6, 7, 8 and 9 were then made, the coke being decreased, while the blast pressure was increased each day, resulting in a decided increase in the melting speed. Tables 5, 6, 7, 8 and 9 give the data obtained from these tests.

TABLE 5

Total iron melted, tons	24.25
Melting rate (blast on to blast off), tons per hour	9.04
Melting rate (iron down to blast off), tons per hour	9.66
Time before iron comes after blast is on, minutes	10
Iron melted per minute per square foot cupola area, based on iron down to blast off (54 inches diameter), pounds	20.25
Iron melted per minute per square foot cupola area, based on iron down to blast off (50 inches diameter), pounds	23.62
One pound coke melts how many pounds iron (including bed)	8.94
Blast pressure, ounces	9.80
Cupola area is how many times twyer area (small end):	
At 54 inches diameter cupola	5.98
At 50 inches diameter cupola	5.13
Bottom of melting zone above top of twyer, inches	12–14
Weight of iron layer is how many times weight of coke layer	13.33
Time between starting fire and starting blast, hours and minutes	2:30

TABLE 6

Total iron melted, tons	22.65
Melting rate (blast on to blast off), tons per hour	9.39
Melting rate (iron down to blast off), tons per hour	10.24
Time before iron comes after blast is on, minutes	12
Iron melted per minute per square foot cupola area, based on iron down to blast off (54 inches diameter), pounds	21.44
Iron melted per minute per square foot cupola area, based on iron down to blast off (50 inches diameter), pounds	25.01
One pound coke melts how many pounds iron (including bed)	8.71
Blast pressure, ounces	9.86
Cupola area is how many times twyer area (small end):	
At 54 inches diameter cupola	5.96
At 50 inches diameter cupola	5.13
Bottom of melting zone above top of twyer, inches	10–14
Weight of iron layer is how many times weight of coke layer	13.33
Time between starting fire and starting blast, hours and minutes	2:30

TABLE 7

Total iron melted, tons	24
Melting rate (blast on to blast off), tons per hour	9.60
Melting rate (iron down to blast off), tons per hour	10.43
Time before iron comes after blast is on, minutes	12

Iron melted per minute per square foot cupola area, based on iron down to blast off (54 inches diameter), pounds	21.82
Iron melted per minute per square foot cupola area, based on iron down to blast off (50 inches diameter), pounds	25.45
One pound coke melts how many pounds iron (including bed)	9.02
Blast pressure, ounces	10.00
Cupola area is how many times twyer area (small end):	
At 54 inches diameter cupola	5.98
At 50 inches diameter cupola	5.13
Bottom of melting zone above top of twyer, inches	10–14
Weight of iron layer is how many times weight of coke layer	13.33
Time between starting fire and starting blast, hours and minutes	2:30

TABLE 8

Total iron melted, tons	20.30
Melting rate (blast on to blast off), tons per hour	9.75
Melting rate (iron down to blast off), tons per hour	10.91
Time before iron comes after blast is on, minutes	13
Iron melted per minute per square foot cupola area, based on iron down to blast off (54 inches diameter), pounds	22.95
Iron melted per minute per square foot cupola area, based on iron down to blast off (50 inches diameter), pounds	26.77
One pound coke melts how many pounds iron (including bed)	9.02
Blast pressure, ounces	10.13
Cupola area is how many times twyer area (small end):	
At 54 inches diameter cupola	5.98
At 50 inches diameter cupola	5.13
Bottom of melting zone above top of twyer, inches	10–12
Weight of iron layer is how many times weight of coke layer	14.28
Time between starting fire and starting blast, hours and minutes	2:15

TABLE 9

Total iron melted, tons	23.85
Melting rate (blast on to blast off), tons per hour	10.36
Melting rate (iron down to blast off), tons per hour	11.35
Time before iron comes after blast is on, minutes	12
Iron melted per minute per square foot cupola area, based on iron down to blast off (54 inches diameter), pounds	23.77
Iron melted per minute per square foot cupola area, based on iron down to blast off (50 inches diameter), pounds	27.73
One pound coke melts how many pounds iron (including bed)	10.02
Blast pressure, ounces	10.55
Cupola area is how many times twyer area (small end):	
At 54 inches diameter cupola	*5.98
At 50 inches diameter cupola	5.13
Bottom of melting zone above top of twyers, inches	10–12
Weight of iron layer is how many times weight of coke layer	15.38
Time between starting fire and starting blast, hours and minutes	2:45

* Iron too dull on account of too small coke charges.

7 During test 9, however, it was noticed that the iron was not at the proper temperature, so for the next test, 10, the coke was increased without altering the blast pressure. This resulted in a decreased melt per hour.

TABLE 10

Total iron melted, tons	22.35
Melting rate (blast on to blast off), tons per hour	10.25
Melting rate (iron down to blast off), tons per hour	11.17
Time before iron comes after blast is on, minutes	11
Iron melted per minute per square foot cupola area, based on iron down to blast off (54 inches diameter), pounds	23.39
Iron melted per minute per square foot cupola area, based on iron down to blast off (50 inches diameter), pounds	27.29
One pound coke melts how many pounds iron (including bed)	9.49
Blast pressure, ounces	10.55
Cupola area is how many times twyer area (small end):	
At 54 inches diameter cupola	*5.98
At 50 inches diameter cupola	5.13
Bottom of melting zone above top of twyer, inches	10–12
Weight of iron layer is how many times weight of coke layer	14.28
Time between starting fire and starting blast, hours and minutes	2:30

* Iron rather dull, coke charge should be increased from 140 to 150 pounds.

8 The remainder of the tests which have been made have not been tabulated, but it has been found that a coke charge of 150 pounds, with a blast pressure of 10½ ounces results in a melt of between 11 and 11½ tons per hour, the iron coming down at the proper temperature.

9 We believe that the changes which are responsible for the increase of our melting rate, were the enlargement of the twyer openings and the decrease of our coke charges, the enlargement of the twyer openings making it possible for us to get the necessary air into the cupola without burning more coal under our boiler, and the decrease of the coke charges resulting in a saving of one-half ton per each 25 tons of iron melted.

10 A close study of cupola action indicates at once why an excess of coke decreases the melting rate. Iron in the cupola is melted in a fixed zone, the first charge of iron above the bed being melted by burning coke in the bed. As this iron is melted, the charge of coke above it descends and restores to the bed the amount which has been burned away. If there is too much coke in the charge, the iron is held above the melting zone above referred to, and the excess coke must be burned away before it can be melted and this of course decreases the economy and the melting speed.

Mr. H. M. Lane The discussion of this paper has naturally included cupola practice to some extent, and in the matter given by Messrs. Fortune and Wells a number of points are touched on which it may be well to emphasize.

2 The experiments performed show conclusively that better result were obtained by increasing the area of the twyers. This is in accordance with the facts which might be expected from a knowledge of the principles of the combustion which takes place in the cupola. The only reason that blast pressure has to be used is to overcome the resistance which the gases meet with in passing through the charge, and also to overcome the resistance of the pipes and passages leading to the cupola. The power necessary to overcome this resistance represents an expenditure of energy. The compression of the air to high pressures always absorbs power, and hence if we can arrange to deliver the same number of pounds of air to the cupola at a lower pressure we will save the coal pile in the boiler room and have more uniform results from the cupola.

3 This points to the use of large twyer areas and low blast pressures. With the ordinary height of cupola, however, these pressures will usually run at least ten ounces; hence it is simply a question of practice as to whether a positive or fan blower shall be used. With properly designed twyers, either will give good results. With poorly designed and proportioned twyers the positive blower will give the best results, on account of the fact that it tends to overcome the difficulties introduced by bad twyer design.

The Author It was not the purpose of this paper to present the actual results of specific tests; relative performances only are shown as indicative of average conditions and results. Air was not assumed as an incompressible fluid, but allowance is made in the formula for its change of density relatively to the pressure. The significant figures are given because so calculated by the given formula. It is merely a matter of opinion whether round numbers should be substituted. The formula employed and the results given are those generally accepted by blower manufacturers.

No. 1176

PATTERNS FOR REPETITION WORK

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A pattern which is run continuously for months, or perhaps years, clearly falls within the limits of this paper as being used for repetition work. And it is just as clear that one which is discarded after a single casting has been made from it should be classed as a pattern for jobbing work.

2 The exact point which marks the division between them depends in a large measure, upon the size of the foundry and the kind of work it handles, and the two classes frequently merge into each other by imperceptible gradations. Without attempting to fix specific limits, we can use the extreme cases cited above to indicate the lines along which the distinction should be drawn, leaving each pattern user to decide for himself as to the precise position on the scale which he assigns to any given pattern.

3 It is this position which usually determines the expenditure that can be permitted in making the pattern, for it is evident that a cost which would be perfectly legitimate for making say a million castings, might be excessive if only ten thousand were required, and entirely prohibitive for one thousand. On the other hand, the circumstances might be such as to justify a high pattern cost, even for a small number of castings, as for instance, in the case of certain master patterns, further reference to which will be made elsewhere in this article.

4 Many of the conclusions reached in this paper may be borne in mind to good advantage even in the case of jobbing patterns. But the very nature of the service for which these are intended is such that the designer must leave most of the details to the judgment of the pattern maker; and if the latter fails to catch every important point, it simply means that the moulder may have to spend some addi-

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tional time in producing the desired casting from the pattern furnished him. For whatever use the pattern is intended, the problem resolves itself into a question of distributing the total work in such a way as to attain the greatest economy in the final result.

5 Actual observation of the practical working of different methods of producing patterns has convinced the writer that no pattern which can be legitimately classed as being used for repetition work should ever be made except from a drawing which looks like the pattern, and gives the actual dimensions of the pattern itself. Mention is made of the fact that the drawing should look like the pattern, for the reason that, on small work, the allowances for shrinkage, finish and draft may make the appearance of the pattern quite different from that of the finished piece.

6 In making patterns for repetition work, micrometer calipers, vernier calipers, height gages, etc., are constantly called into requisition, and as it would be both expensive and confusing to attempt to duplicate these in different shrinkage scales, it becomes necessary to work to figures which include the necessary allowances for shrinkage. To the man who is accustomed to big work on which a quarter of an inch is close, and a thirty-second is the very height of refinement, it may seem absurd to use thousandths in measuring patterns. But there are many cases in repetition work where this degree of accuracy is not only desirable but absolutely essential.

7 As an example of the effects of shrinkage and finish, let us assume that we wish to produce the piece shown in the upper part of Fig. 1, the marks *f* indicating finished surfaces.

8 The lower part of Fig. 1 shows the actual pattern dimensions, assuming,

$$\begin{array}{ll} \text{Shrinkage per inch of length,} & S = 0.01 \text{ inch} \\ \text{Allowance for finish,} & F = 0.04 \text{ inch} \end{array}$$

In this particular case, the various combinations of shrinkage and finish modify the final 4 inch dimensions so as to produce dimensions of 3.96 inches, 4.00 inches, 4.04 inches, 4.08 inches and 4.12 inches on the pattern.

9 In actual practice, the dimensions would not usually be strung out in one continuous line as in Fig. 1, but would probably double back on themselves to some extent. In addition, the shape of the casting might be such as to make the shrinkage irregular; it might be desirable to allow more finish at certain surfaces than at others, and it might be necessary to make additional allowances for draft.

10 In view of all the factors to be considered, the determination of the pattern dimensions by a process of mental arithmetic may be an excellent athletic exercise for the brain, but it is not a problem which a mechanic should be called upon to solve during working hours.

11 It is also necessary to remember that very few machinists or tool makers have much detailed knowledge of foundry practice, and that the trade of metal pattern making is still comparatively new. Patterns made and carded according to the best judgment of a tool maker have often been entirely rebuilt after the first attempt to run

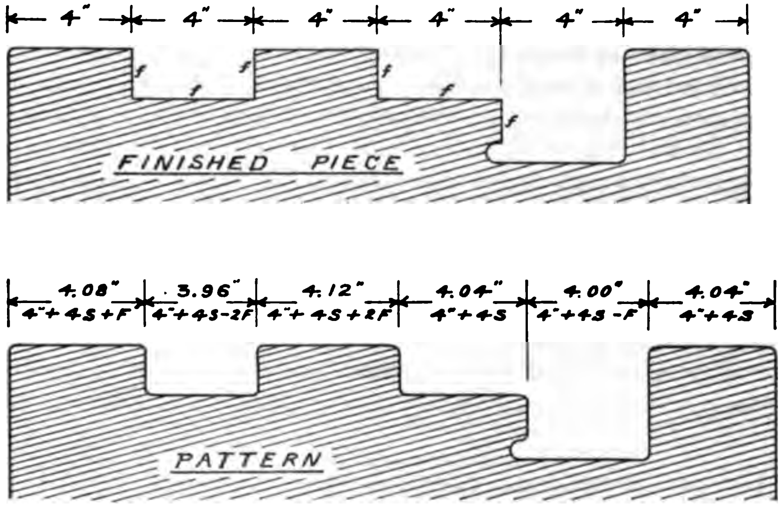


FIG. 1 ALLOWANCES FOR SHRINK AND FINISH

them in the foundry. Of course such occurrences indicate lack of coöperation, but the only practical way to secure effective coöperation is to prepare a drawing which records the decision reached after due consideration by all the interested parties.

12 There is no doubt but that the best and most economical results are obtained by using men who are skilled in working accurately to drawings, and then supplying them with drawings which they can follow absolutely. Even if it were possible for the workman to carry in his head the various allowances required on a pattern, the lack of a record covering them would lead to endless trouble and confusion. If a pattern has to be duplicated or replaced, the worn one must either be copied as closely as possible, or the workman, who may or may not be the author of the original pattern, must introduce a new

set of allowances. And while it sounds simple to tell a man to "make another just like this," we all know how the little errors accumulate until the final result is startlingly different from the original. It is said that a Chinaman can and will copy a model with absolute fidelity, but no one has ever had the hardihood to make a like assertion in regard to a workman of any other nationality.

13 For computing shrinkages, the drawing room should be furnished with a table giving the shrinkage per inch (in hundredths or thousandths of an inch) for each of the materials commonly used. This shrinkage, multiplied by the length in inches of any part of the casting, gives the allowance in inches direct. It may seem superfluous to explain this apparently self evident procedure, but the author has seen cases in which the shrinkage was expressed in fractions of an inch per foot of length and in which each dimension was carefully translated into decimals of a foot before multiplying by the constant.

14 It will frequently happen that there are certain parts of a casting where a high degree of accuracy is not necessary, and a very little time spent by the drawing room in determining and indicating these points will be amply repaid by the saving in making the patterns. The required degree of accuracy can best be indicated by means of the number of decimal places in the figure giving the dimension. In using this method there must be an understanding between the drawing room and pattern maker that the permissible error is never greater than one in the last decimal place. For instance,

1.127 indicates a permissible error of 0.001 inch ±
1.120 indicates a permissible error of 0.001 inch ±
1.12 indicates a permissible error of 0.01 inch ±
1.10 indicates a permissible error of 0.01 inch ±

15 Reference to the Fig. 2 to 14, illustrating the various methods of carding, and to Fig. 15 to 25 illustrating the location of the parting line, will show that many different arrangements for draft are possible, although only one may be desirable. The pattern drawing should therefore show where the parting comes, and should indicate the amount of draft to be allowed at different points. The allowances for draft are discussed in detail under a separate heading.

16 A carding drawing should be prepared in conjunction with the drawing of the pattern itself. These must be carried along together, as a change in one will usually affect the other. The carding drawing should show clearly the arrangement of the runner, the enlarged portion of the runner where the sprue is to be cut, the location and size of the gates, the points at which they join the patterns,

the arrangement of the patterns, the location and size of risers or shrink balls, if used, and the connections, if any, which may be needed in addition to the gates for supporting the patterns. It may really be looked upon as an assembly drawing, and will usually require only a few dimensions.

17 To avoid the confusion which might arise if carding drawings sometimes show the drag side and sometimes the cope side, it is well to adopt the rule of showing all cardings as they would appear when looking at the drag side. In the case of an "open" carding, this rule causes the pattern to be shown as it appears when looking down on it as it lies on its mold board.

18 Turning now from the general requirements, we may, for convenience, group under the following headings those details which involve a consideration of the peculiarities of each individual case:

- A The number of patterns to be grouped in one card and the size of the flask.
- B The method of carding, whether mounted on a "plate" or as a "split" pattern, or "open" for use with a mold board, etc.
- C Location of the parting line.
- D Allowances for draft.
- E Arrangement of the gates, runners, risers and supporting connections.
- F The material of the pattern, and of the runner, plate, mold board, etc.
- G The points on the pattern at which special accuracy is required.
- H The amount of work to be expended on the pattern.

19 These in turn depend on the given conditions which may be tabulated as follows:

- *a* The size and shape of the casting.
- *b* The special requirements, if any, which may call for placing the pattern in a certain position or for providing risers, shrink balls, etc., in order to secure sound castings.
- *c* The machining operations to be performed on the casting.
- *d* The locating points for these operations.
- *e* The points at which fillets and rounds are required.
- *f* The degree of accuracy needed at unmachined portions and points, if any, where special accuracy is required.
- *g* The rate at which the castings are to be produced.
- *h* The probable total number required.

i The probable length of the intervals during which the pattern is out of use, and the conditions under which it is stored during these intervals.

20 Having determined the considerations affecting the design and construction, we may consider them in detail.

THE NUMBER OF PATTERNS TO BE GROUPED IN ONE CARD, AND THE SIZE OF THE FLASK

21 For snap flask work it is usually necessary to allow a wall of sand about one inch thick outside of the extreme points of the patterns. If the card consists of a number of small patterns, the walls of sand between them tie into the outer wall and help to support it. Under these conditions no further support is necessary for castings extending say ½ inch or less above or below the parting line. If the castings are deeper, or if there is a considerable length of outer wall which is not supported by other walls tying into it, a band may have to be provided, but the one inch dimension may still be maintained. In most cases the work of handling the band is less than the work of handling the increased amount of sand required by a larger mold. Even if iron flasks are used, the one inch dimension should generally be adhered to, as there is apt to be trouble in ramming, and danger of the flask acting as a chill if the outer wall of sand is reduced much below that figure.

22 Unfortunately the manufacturers of foundry supplies seem to have made no attempt whatever to select certain sizes of flasks which can be looked upon as standard, and therefore given the preference whenever circumstances permit. Their catalogues usually state that they will make any size of flask desired, but this does not help the man who is endeavoring to standardize his equipment.

23 Special sizes can never be entirely avoided, but the author recommends the general adoption of two sizes which have proved very convenient for small snap flask work. The smaller of these, 9 by 16 inches, inside measurement, is the best all round flask for work within its range. The larger one, 10 by 18 inches, inside measurement, is nearly as convenient, and there is no serious objection to its use, provided it permits of a more advantageous grouping for a given pattern. There is, however, a limit beyond which the increased weight of each mold more than offsets the advantage secured by the reduction in the number of molds. Experience shows that the output with a mold 9 by 16 inches is just about equal to the output with a mold 10 by 18 inches holding one-third more castings. Whether or

not the larger flask will increase the capacity more or less than this amount can be determined only by laying out the possible groupings for each size.

24 Whenever there is a choice between any two sizes and their outputs are practically equal, the preference naturally rests with the smaller one as involving the smaller expense for patterns, flasks, etc.

25 In fixing the length and width of a flask, the designer has usually some latitude as he can vary the grouping of his patterns, but the depths of the drag and cope are less under his control. As the sand in the drag is never called upon to support its own weight, the depth of the drag need never be greater than is necessary to provide sufficient sand (say 1½ inches after ramming or squeezing) below the deepest portion of the pattern. The depth of the cope must be sufficient to give a corresponding amount of sand above the pattern, and it must also be sufficient to make sure that the sand will support its own weight when the cope is lifted. The depth of the cope will sometimes be fixed by one and sometimes by the other of these requirements.

TABLE 1 MINIMUM DEPTH OF FLASK

SIZE OF FLASK IN INSIDE MEASUREMENTS	MINIMUM DEPTH OF FLASK GIVING A COPE THAT CAN BE LIFTED	APPROXIMATE DEPTH OF COPE HALF OF MOLD
9 by 16 inches	3 inches	1⅞ inches
10 by 18 inches	3¼ inches	2 inches
12½ by 17½ inches	3½ inches	2⅛ inches
13½ by 15½ inches	3¾ inches	2¼ inches
14 by 23 inches	4 inches	2⅜ inches

26 If the ramming is done by hand, the mold is struck off flush with the flask, and the depth of the latter corresponds with the desired depth of the mold. If the mold is squeezed by power, the flask must be deeper than the desired depth of the mold by an amount equal to the squeeze. The squeeze may be figured as about four tenths of the original average depth of loosely packed sand.

27 If the pattern is mounted in a frame, the depth of the drag half of the flask must be further corrected by deducting an amount equal to the thickness of the frame. The frame should always be considered as belonging to the drag half of the flask.

28 Table 1 gives the minimum depth of flask which experience has shown to be permissible for a cope, squeezed by power, in order that the sand may support its own weight.

29 If the conditions require a deep flask, or one which is larger than either of the two sizes mentioned, care should be taken whenever possible to avoid molds beyond the capacity of a single operator.

30 For snap flask work the limits for a one-man mold are about as follows:

A Width 12 inches inside of flask. A greater width makes the mold liable to tip toward or from the operator.

B Length 24 inches inside of flask. A greater length requires an excessive spread of the arms.

C Weight 85 pounds corresponding roughly, for flasks of average depth, to an internal flask area of 250 square inches.

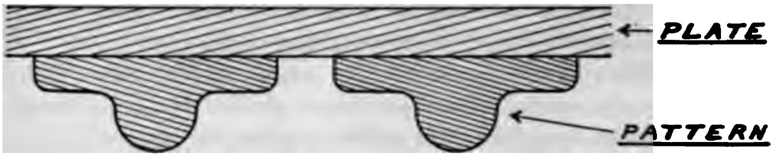


FIG. 2 "PLATE" PATTERN

31 Care should be exercised to avoid molds which are square or nearly square, as they are liable to tip, even if the width is less than the 12 inches specified above. The best shape is obtained when the width is from $\frac{5}{10}$ to $\frac{6}{10}$ of the length.

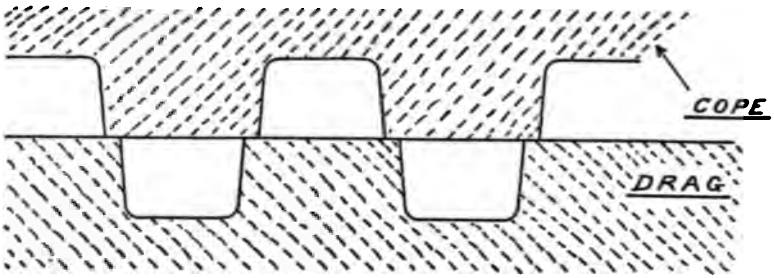


FIG. 3 CASTINGS STAGGERED IN DRAG AND COPE

32 When carrying a mold supported by a solid flask the operator can rest it against his body, whereas a mold from which the flask has been removed must be swung free from all danger of contact. For this reason solid flasks may be somewhat larger than snap flasks in spite of the fact that the flask itself has to be handled in addition to the mold. The permissible increase may be taken at about 10 per cent in length, 30 per cent in width, and 50 per cent in weight.

33 Although output is an important consideration, we must not lose sight of the fact that it is not the sole determining factor in selecting a flask size. If the required rate of production is low and

the probable total requirements small, it may pay better to mount a few patterns on a small card in preference to carding even a considerably increased number for a slightly larger flask. Further reference to this will be made under heading "The amount of work to be expended on the pattern."

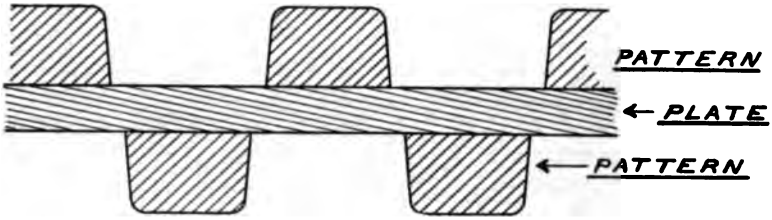


FIG. 4 "STAGGERED PLATE" PATTERN

34 Every possible care should be exercised to limit the numbe of different sizes of flasks. A record should be kept of all existing sizes, and no new size should be created unless it is perfectly certain that none of the old ones are suitable.

35 It will nearly always be a safe rule to use a plate whenever the pattern permits. It gives the most durable construction, and

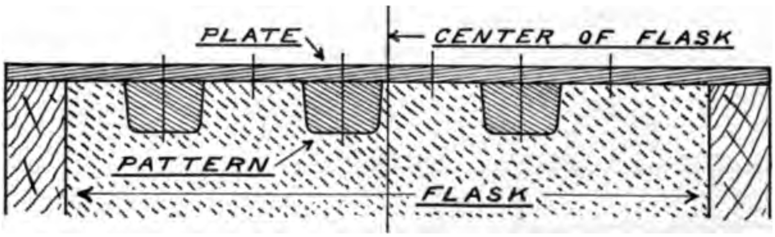


FIG. 5 "REVERSIBLE PLATE" PATTERN

THE METHOD OF CARDING

except in special cases, such as those shown in Fig. 5 and 11, it permits of making both halves of the mold at once. The simplest case arises when one side of the pattern is flat, permitting it to be mounted as shown in Fig. 2.

36 If, instead of being shallow, the pattern is deep, a considerable space must be left between adjoining patterns to give a sufficient wall of sand. In such a case a saving can be effected by putting the patterns alternately above and below the parting line as in Fig. 3. This can be arranged in two ways; by actually mounting patterns on both sides of the plate, as in Fig. 4, or by making only half the num-

ber of patterns and mounting them on one side as shown in Fig. 5.

37 It is evident that if the first half mold made is used as the drag and the next one turned over and placed on it as the cope, the desired staggering will be obtained. This style of plate is sometimes known as a "reversible plate," although, strictly speaking, it is the mold and not the plate that is reversible.

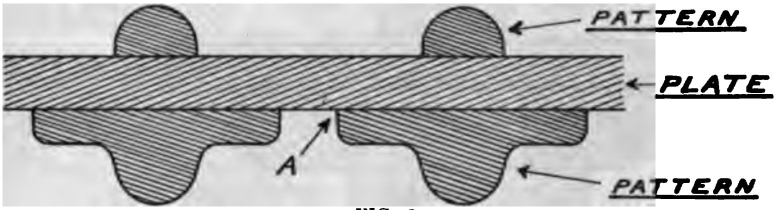


FIG. 6
"PLATE" PATTERN WITH PORTIONS OF PATTERN ON EACH SIDE OF PLATE

38 The first method gives the greater output, as both halves of the mold may be made at once. It is to be preferred for shallow patterns of simple form, as it obviates the necessity for special accuracy in locating the patterns and keeping flask pins true. If the pattern is complicated, a decided saving in pattern cost can be effected by using the second method. If the pattern involves a deep draw, the second method is again to be preferred, as it requires only the lifting of the pattern from the sand, and not the lifting of the cope

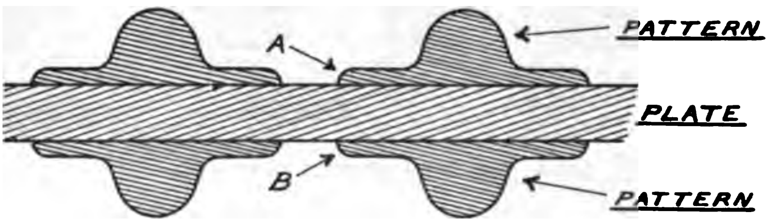


FIG. 7
"PLATE" PATTERN CALLING FOR ACCURATE MATCHING OF DRAG AND COPE

off of the pattern. The "reversible" method has the disadvantage which may in some cases prove serious, of producing half the castings under one set of gating and cooling conditions and half under another set. This is referred to in further detail.

39 Careful work to make the two sides of the plate match, and to keep the flask pins true is necessary if portions of the pattern have to be mounted on opposite sides of the plate. If a square corner is permissible at *A*, they may be mounted as in Fig. 6. If a round corner is required at both *A* and *B*, they must be mounted as

in Fig. 7. The staggered arrangement can also be used for patterns extending on both sides of the parting line as in Fig. 8.

40 In order that the two halves of the mold may meet properly the vertical distance between the upper and lower faces of the plate

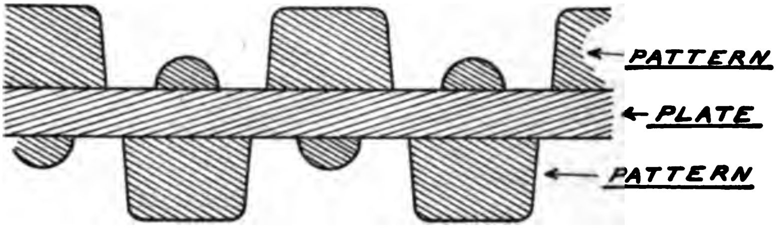


FIG. 8
"Staggered Plate" Pattern with Portions of Pattern on Each Side of Plate

must be constant throughout, excepting at certain points where an excess thickness is purposely provided, as referred to later. This condition can be easily met if the parting surface is a plane, but prohibits the use of a plate if this surface assumes a complicated shape. If the surface can be given some simple geometrical form

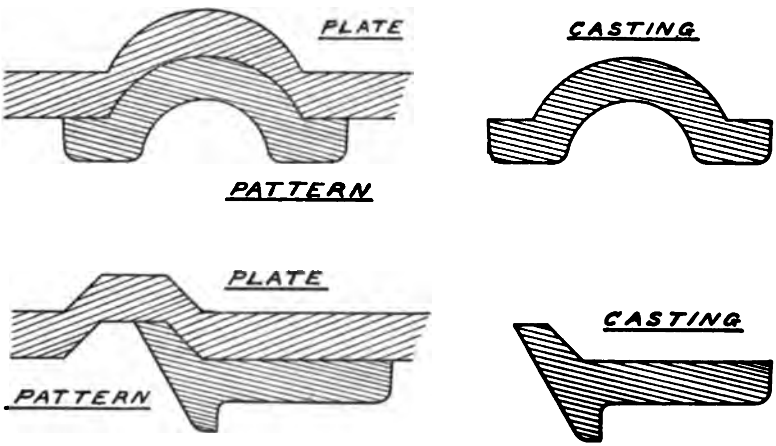


FIG. 9
"Plate" Patterns in Which the Parting Surfaces are not Plane

which can be easily machined, a plate can often be used to good advantage even if the parting is not in a single plane. Several cases of this kind are illustrated in Fig. 9.

41 In making such plates, the best results will be obtained if a little extra thickness is given to the plate at any points where an exact fit of the mold is not required. For example, in the first of the

patterns shown in Fig. 9, the different sections through the molds should appear as shown in Fig. 10.

42 The "split" pattern is really a modification of the patterns shown in Fig. 6, 7 and 8, which is used if the draw is so deep that the

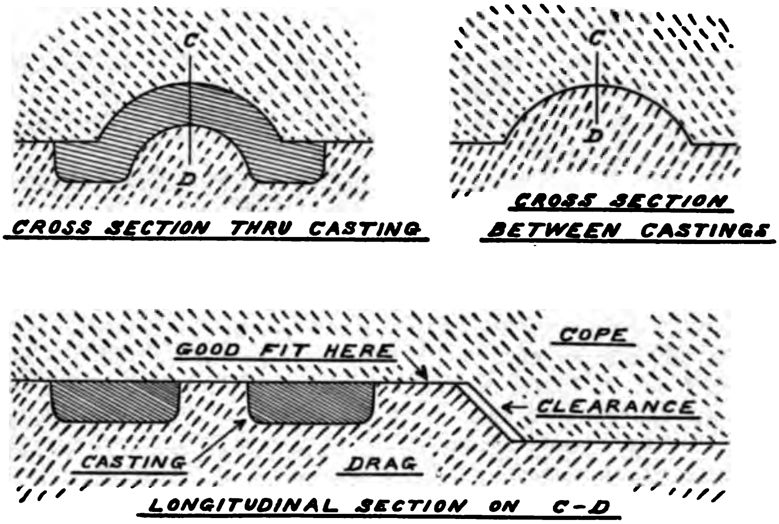


FIG. 10 CLEARANCE AT UNIMPORTANT PORTIONS OF PARTING SURFACE

cope can not well be lifted off of the pattern. In such a case the pattern is split, each half being separately mounted as in Fig. 11. The pattern is lifted from the drag and also from the cope, and the latter is turned over and set on the drag, making the completed mold

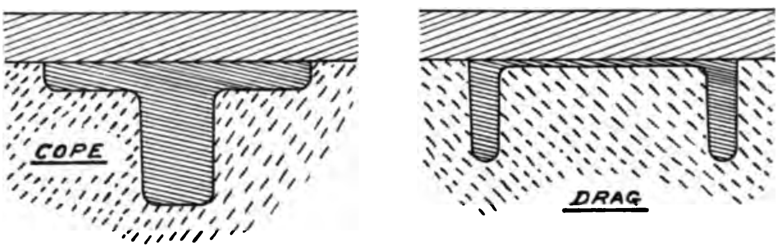


FIG. 11 "SPLIT" PATTERN

appear as in Fig. 12. If used with a stripping plate the principle is the same, only the patterns are reversed and drawn downward through the plate, instead of being lifted up. If the casting happens to be symmetrical about the parting line, a single pattern can be used for both the drag and cope.

43 If the parting surface is too irregular for a plate the ordinary pattern connected to a runner and provided with additional supports, if necessary, must be used, so as to make an "open" carding. As this construction gives no backing to the pattern, a separate support must be provided in the form of a mold board. The use of the mold board makes it impossible to ram up both halves of the pattern at once. If power squeezers are used with this style of pattern, special care must be taken to give the drag a heavy squeeze and the cope a light one. If this precaution is not observed the pattern will be sprung, and pressed still further into the drag half, when the cope is squeezed. When ramming by hand there is less danger of springing as the support afforded by the drag has to resist only the localized blow of the rammer instead of a pressure exerted simultaneously over the entire parting surface.

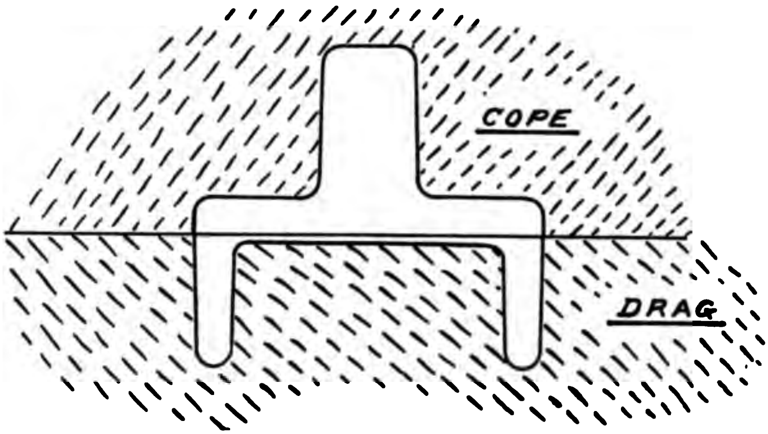


FIG. 12 MOLD MADE FROM "SPLIT" PATTERN

44 If the molds are squeezed by power, it is desirable to put cleats under the mold board so that the total height will be such as to keep the idle portion of the stroke as small as possible at all times.

From Fig. 13

$$A + x = B + C$$

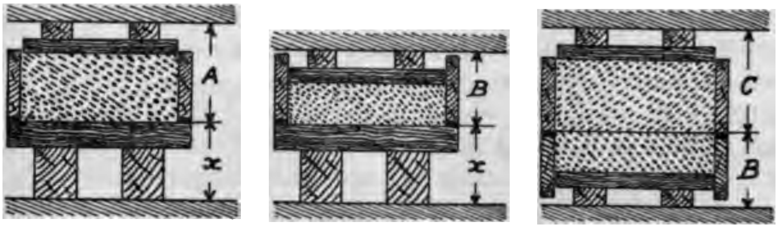
it follows that

$$\text{Desired height of mold board, } x = B + C - A$$
$$= C - (A - B)$$

where C is the combined height of cope and squeezing board before squeezing, and $A - B$ is the amount of squeeze in the drag.

45 Locating the cleats so as to reduce the deflection of the mold board to a minimum is a matter which deserves attention, particularly

in the case of long flasks. It may be assumed that the pressure exerted on the mold board through the sand is practically uniform at all points, and the mold board may therefore be treated as a girder, resting on two supports and uniformly loaded as shown in Fig. 14.



Ready to squeeze drag After squeezing drag Ready to squeeze cope

FIG. 13 HEIGHT OF MOLD BOARD

46 For a pressure of P pounds per inch of length, the deflections may be represented as follows:

$$\text{Deflection at ends of mold} = \frac{P\left(\frac{L-D}{2} - W\right)}{8} \; \frac{\left(\frac{L-D}{2} - W\right)^3}{E\,I}$$

$$\text{Deflection at center of mold} = \frac{P\,D}{384} \; \frac{D^3}{E\,I}$$

Placing these equal to each other, and solving we get

$$D = \frac{\sqrt[4]{3}}{\sqrt[4]{3} + 1} \; (L - 2\,W)$$

$$D = 0.568 \quad (L - 2\,W)$$

47 The cleats on the bottom boards and squeezing boards should be centered with the cleats on the mold boards. The thickness of the squeezing board and of the bottom board, including the cleats in both cases, must be greater than the distance traveled in squeezing. The middle view in Fig. 13 will make this clear.

LOCATION OF THE PARTING LINE

48 The location of the parting line, both with reference to the pattern itself, and with reference to the edges of the flask, is highly important, and the judgment used in its selection may make the

whole difference between success and failure in producing the molds. In locating it we should be governed by these rules:

A Avoid steep inclines in the abutting surfaces of the drag and cope. Always keep these surfaces as nearly square to the line of lift as possible.

B Avoid unsupported projections of sand, particularly in the cope. Avoid hanging pockets of sand in the cope.

C Make the draw in lifting the cope as small as possible.

D Where a draw in the cope is unavoidable, endeavor to keep it up within the flask so that the latter will support it.

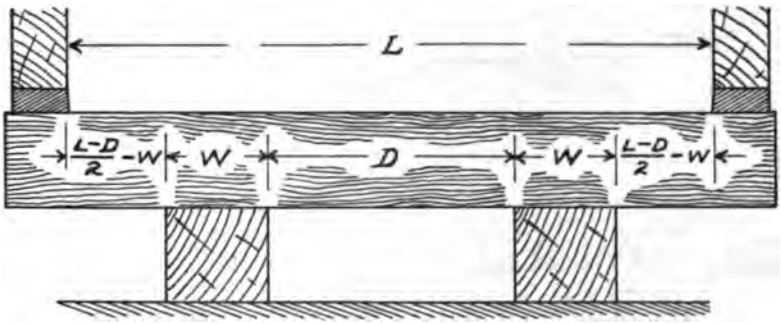


FIG. 14 SPACING OF CLEATS

E When practicable, avoid a parting surface which intersects a face of the casting. Give the preference to a parting which forms a continuation of a face even if a rounded corner has to be sacrificed.

F If a mold board is used, avoid exposed joints between it and the pattern.

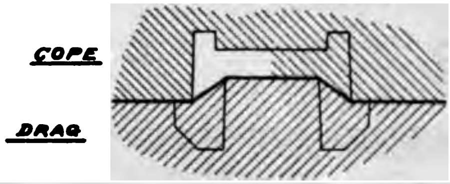
49 Following these rules the first of the partings shown in Fig. 15 to 19 inclusive are the ones to be preferred in each case. Partings similar to those shown in Fig. 20 to 24 inclusive should be used only if necessary, and of the two partings shown in Fig. 25 the first is to be preferred.

50 Fig. 15 illustrates the avoidance of the steep incline at *A* and of the hanging pockets of sand at *B* and *C*. Fig. 16 illustrates the avoidance of the unsupported projections of sand at *D* and of the hanging pocket of sand at *E* and *F*. Fig. 17 and 18 illustrate again the avoidance of hanging pockets of sand at *G*, *H*, *J* and *K*, and Fig.

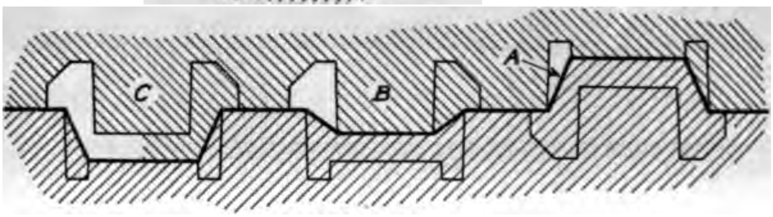
15 to 19 inclusive illustrate the features of keeping the draw in the cope as small as possible, and of keeping it up inside of the flask.

51 It is interesting to note that the application of these rules results, in different cases, in locating the casting in each of the three possible positions in the mold, namely: entirely within the cope, as in Fig. 17; partially in the cope and partially in the drag as in Fig. 18; and entirely in the drag as in Fig. 19.

52 Fillets and rounded corners are such excellent things—in their proper places—and their importance has been written about and talked of so much, that we are sometimes led into calling for



Correct parting



Incorrect parting

FIG. 15

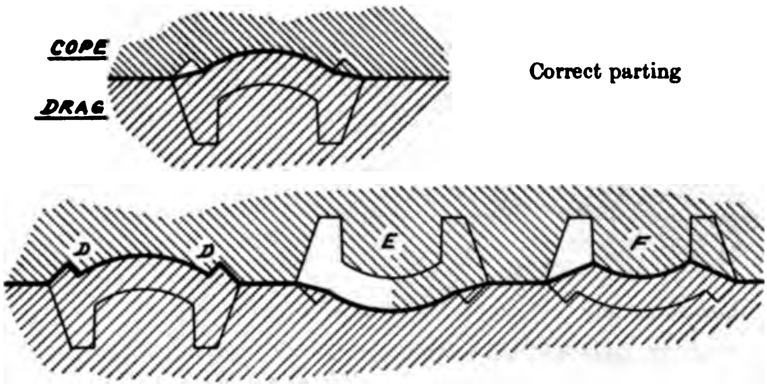
AVOIDANCE OF STEEP INCLINES IN PARTING SURFACE AND OF HANGING POCKETS OF SAND

them in places where they are of no help to the casting, and really become very objectionable on the pattern.

53 For instance in the very simple pattern shown in Fig. 2. If it were absolutely necessary to round all the corners it would have to be mounted as shown in Fig. 20, adding extra expense to the making of the pattern, and making it necessary to exercise constant vigilance to keep the flask pins true.

54 If it were permissible for the corners B and C of Fig. 20 and 21 to be square, the pattern might be mounted as shown in Fig. 21. This would still permit of a round at A. If a fillet were required at C of Fig. 21, it would run out to a feather edge at the upper surface of the plate, and if a smooth and true surface were required at that point of the casting, the pattern would have to be set into the plate

as in Fig. 22. The objection to this fillet applies only to "plate" patterns and not to "open" cardings. If carded "open," the mold and pattern would appear as in Fig. 23. The objection to the double rounded corners, however, holds for the "open" carding as well as

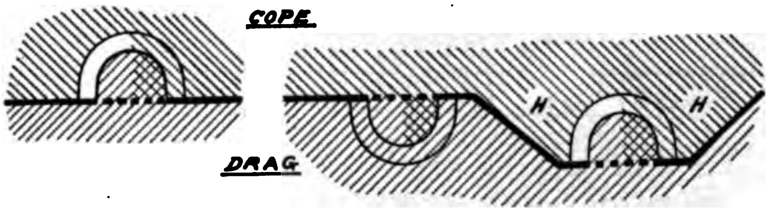


Incorrect parting

FIG. 16
AVOIDANCE OF UNSUPPORTED PROJECTIONS OF SAND AND OF HANGING POCKETS OF SAND.

for the plate, as the cope, instead of being flat, would have to be brought down as shown in Fig. 24.

55 Whenever a rounded corner involves the shifting of the parting line from its best position, an effort should always be made to modify



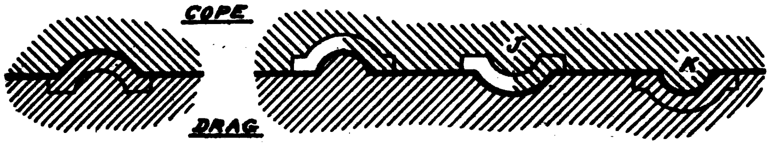
Correct parting Incorrect parting

FIG. 17 CASTING IN COPE

the design so as to permit of a square corner at that point. If the trouble is feared from the chilling of the corner it is well to remember that in hand molding this chilling is more frequently due to wetting the mold than to the actual sharpness of the corner. In machine molding, using well made patterns with ample draft, there should be no occasion whatever for wetting the edges of the mold.

56 In avoiding objectionable projections or hanging pockets of sand, it will be of assistance to bear in mind that the mold board corresponds exactly to the cope, and that all irregularities in one will be reproduced in the other. It is therefore always desirable to keep the mold board as free from such irregularities as may be consistent with the other requirements which have to be met.

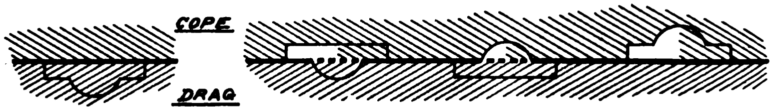
57 In the case of the pattern shown in Fig. 25, it makes little difference, as regards the draw, which side is put in the cope. But



Correct parting Incorrect parting

FIG. 18 CASTING PARTIALLY IN DRAG AND PARTIALLY IN COPE

of the two positions shown the first is to be preferred, as it avoids the exposed joint at *D*. Such a joint requires careful fitting when the mold board is made, and frequent repairs are necessary to maintain its accuracy. By placing the pattern in the first position it covers the recess in the mold board entirely. In this case the recess merely becomes a clearance opening, and no fit is necessary, except perhaps at the bottom, in order to support the pattern and to pre-



Correct parting Incorrect parting

FIG. 19 CASTING IN DRAG

vent it from springing. The first position has the further advantage of requiring the removal of less material from the board. The carving of a mold board is a tedious and expensive hand operation at the best, and every method of reducing this expense is well worth considering.

58 In the foregoing we have considered molding conditions but not casting conditions. A description of the latter would be beyond the scope of this paper, but attention is called to the fact that they

may at times necessitate a departure from the arrangement which would be the most desirable if only the making of the mold had to be reckoned with.

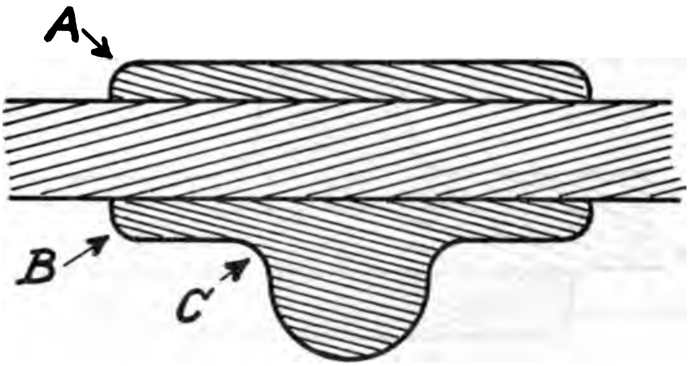


FIG. 20 PLATE PATTERNS WITH ALL CORNERS ROUNDED

ALLOWANCES FOR DRAFT

59 It is necessary that draft toward the parting line be provided in all cases. A smaller draft is permissible when the pattern is lifted from the sand, as in the case of "reversible plate" patterns, "split" patterns, and the drag side of all other patterns, than when the mold is lifted off of the pattern, as in the cope-half of all except "reversible plate" patterns and "split" patterns.

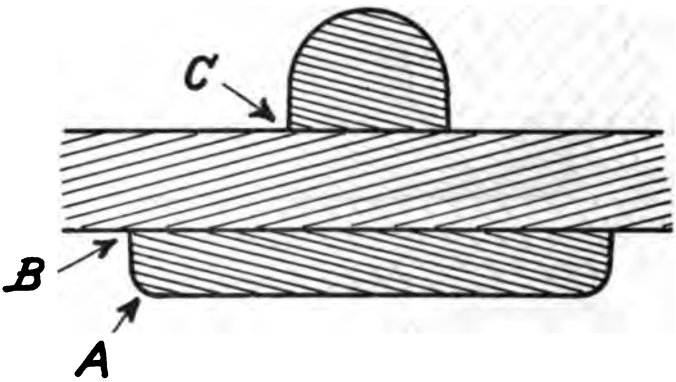


FIG. 21 PLATE PATTERN WITH SOME CORNERS LEFT SQUARE

60 If the draw is shallow, it is usually desirable to express the draft in degrees, but if the draw is deep, it is better to give dimensions for the top and bottom of the taper. In the first case a slight error

in measuring the angle would not sensibly affect the dimensions of the piece, while a slight error in the dimensions might change the draft very considerably. In the second case the conditions are exactly reversed.

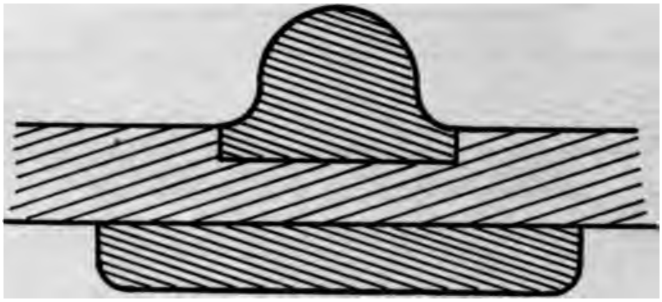


FIG. 22 PATTERN INSERTED IN "PLATE" TO PROVIDE GOOD FILLETS

For those portions of a pattern which are drawn from the sand, the draft should never be less than 1 degree on a side, or 0.02 inch per inch, on a side. If possible it should be about 2 degrees on a side or 0.03 inch to 0.04 inch per inch on a side.

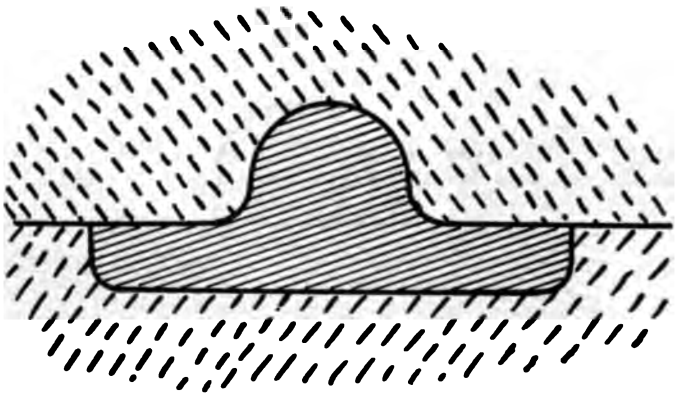


FIG. 23 FILLETS IN "OPEN" CARDED PATTERNS

For those portions of a pattern from which the cope has to be lifted, the draft should never be less than 1½ degrees on a side, or 0.03 inch per inch on a side. If possible it should be about 3 degrees on a side, or 0.05 inch per inch on a side.

ARRANGEMENT OF THE GATES, RUNNERS, RISERS, AND SUPPORTING CONNECTIONS

61 If any portions of the desired casting are very heavy, in comparison with the remaining portions, the gates should be arranged to feed into the heavy parts. The gates should usually be wide and

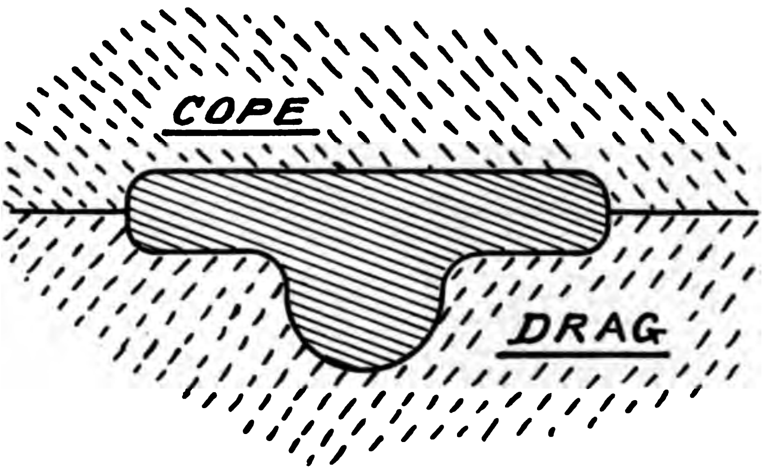
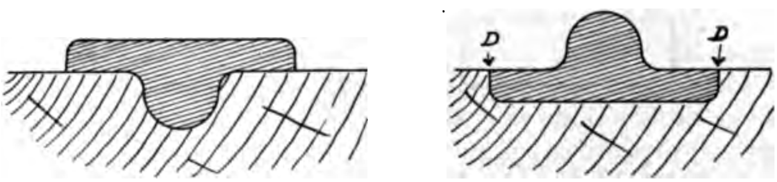


FIG. 24 "OPEN" CARDED PATTERN WITH ALL CORNERS ROUNDED

thin so as to break off easily. If the casting is very light it may be necessary in addition to nick the gate. Care should be taken to leave a good fillet between the nick and the casting itself as shown in Fig. 26 in order to give a clean break at the nick.



Correct parting Incorrect parting

FIG. 25 PATTERNS LET INTO MOULD BOARD

62 To secure uniformity among the castings from any one card, it is desirable to card them all alike, as shown in the upper part of Fig. 27, and not half right and half left, or half at one end and half at the other, as shown in the lower part of the same figure. Shift-

FIG. 26 NICKED GATE

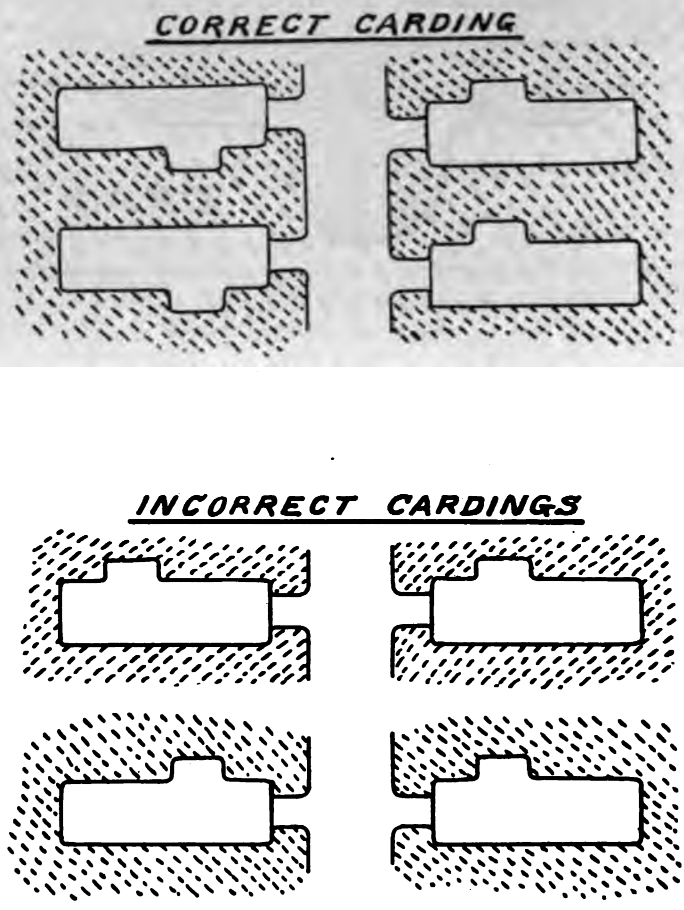


FIG. 27 EFFECT OF CARDING ON UNIFORMITY OF CASTINGS

ing the gate or turning the pattern over may cause variations in the casting, due to the different feeding and cooling conditions. It may also give trouble during machining as the irregularities due to gating come at one point in some of the castings, and at another point in others.

63 To avoid "washing" it is usually desirable to locate the gate in such a way that it will not be in the direct line of flow through the runner. To effect this, the gates may either branch off of the sides of the runner, as in Fig. 27, or if this can not be done, an offset may be provided to check the rush of the metal as in Fig. 28.

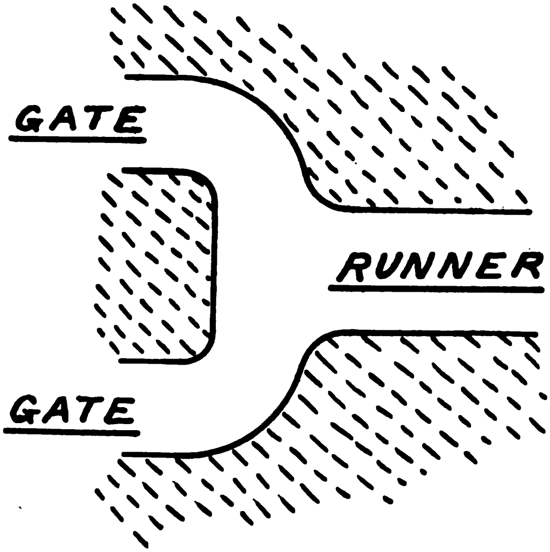


FIG. 28 OFFSET GATES

64 Unless the pouring conditions are such as to require feeding the metal up into the mold from the bottom, the runner should be kept as high as possible, so as to get the best metal into the casting proper. This will usually involve putting the runner into the cope. An excellent cross section for the runner is shown in Fig. 29.

65 The draft on the sides is sufficient to give an easy draw, even though it is in the cope, and the section is heavy enough at all points to prevent danger of chilling. The section, flat on one side and curved on the other, which is sometimes used should be avoided as it is too thin at the edges. A rather neat expedient which sometimes proves helpful is the use of a diamond shaped runner as shown in Fig. 30. If the usual shape of runner had been used, as shown

in Fig. 31, the incline at *A* would have been entirely too steep, and there would have been a very objectionable hanging pocket of sand at *B*. The photograph, Fig. 32, shows a runner in which the draft

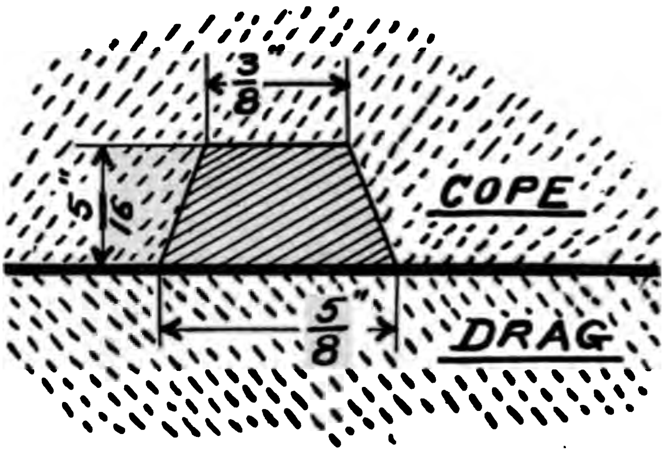


FIG. 29 CROSS SECTION OF RUNNER

was reversed at different points, the mold board rising above the runner in some places, and at others coming only to the bottom of the runner.

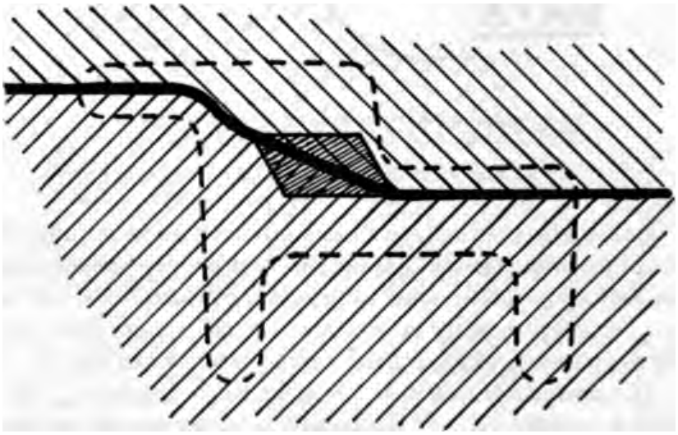


FIG. 30
GOOD PARTING OBTAINED BY USE OF DIAMOND SHAPED RUNNER

66 Fig. 32 also shows an enlargement of the runner at the point where the sprue is to be cut. This enlargement should be about 1 inch in diameter on the cope side. It should be kept in the

exact center of the flask whenever possible, so as to avoid flask weights with pouring holes in special locations. Even if the central location is not possible, the sprue should be kept away from the edge of the flask thus avoiding the danger of the breaking out of the mold.

67 Risers or shrink balls are required only in special cases to avoid piping or excessive shrinkage in heavy parts of the casting. As a discussion of the points at which they are necessary would lead into an entirely unrelated subject, they are merely mentioned here in passing as details which must be provided for when circumstances require them.

68 If the pattern is mounted in a vibrator frame, the latter should always rest on top of the mold board as shown in Fig. 33, and never be let down into it. As the surface of the mold board corresponds

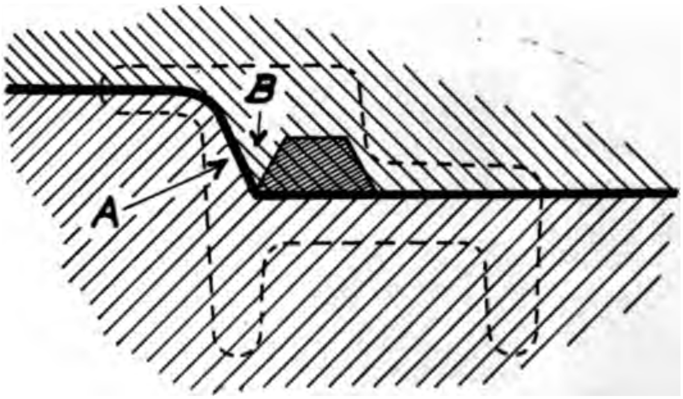


FIG. 31 UNDESIRABLE PARTING DUE TO SHAPE OF RUNNER

to the parting surface, the opening in the vibrator frame must be given draft away from the mold board as shown in Fig. 33.

69 The connection between the pattern and the frame should in almost every case lie on top of the mold board, and should be connected to the frame somewhat as shown in Fig. 34.

70 In snap flask work, it may be necessary to resort to a band in certain cases. This has been treated in detail elsewhere in this article. If a band is placed in the cope it will clear the connection shown in Fig. 34, but if a band is needed in the drag, this form of connection would necessitate a notch in the band at the very point where the plugging of the hole left by the connection leaves the mold the weakest. To avoid this, the connection may be set into the mold board. This will permit the band to come down to the mold board, that is, extend up to the top of the drag, as shown in Fig. 35.

THE MATERIAL OF THE PATTERN AND OF THE RUNNER, PLATE, MOLD BOARD, ETC.

71 For patterns which are used sufficiently to prevent them from rusting, cast iron is by far the best material. It is not only cheap, but it meets the requirements of durability and lightness, and its surface, when free from rust and well waxed, gives a clean draw from the sand. If an iron pattern is out of use for any length of time, it is almost impossible to prevent rust spots, and these spoil the surface very quickly. Of course, the length of time in which an iron pattern may remain idle without rusting depends a good deal on the conditions under which it is stored, and the care taken in cleaning and waxing the pattern before it is put away.

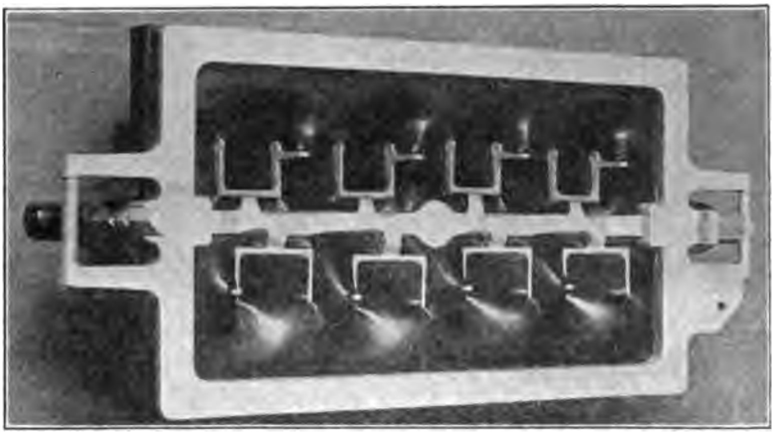


FIG. 32
Use of Diamond Shaped Runner with Draft Reversed at Different Points

72 If a mold board is used, it is usually desirable to keep the pattern and mold board together. When a wooden mold board is used, a very dry atmosphere shrinks and cracks, while even a moderate amount of humidity increases the liability of the pattern to rust. To avoid changes in the mold board the atmospheric conditions in the pattern storage must be made to correspond, as closely as possible, to those in the foundry. This may compel us, in the case of patterns used only at infrequent intervals, to resort to brass, bronze or other alloys, but all of these are heavier than cast iron and the sand has a greater tendency to stick to them. In the case of large patterns they may also be more costly, but in small patterns the possibility of using

commercial shapes, which require little or no machining, may permit of savings which will more than offset the extra cost of the material.

73 Owing to the ease with which they can be soldered or brazed, the above mentioned alloys may sometimes be desirable for a costly pattern in which extensive changes are likely to be made.

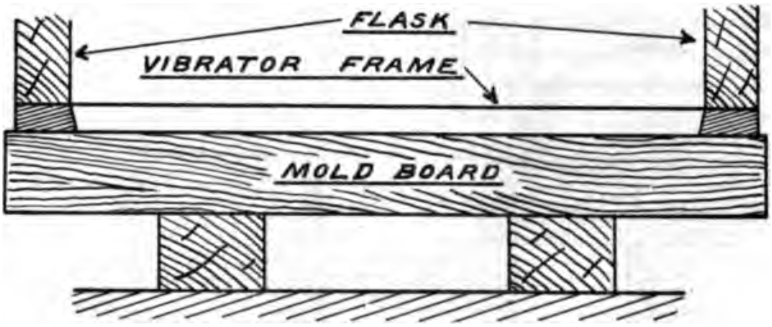


FIG. 33 DIRECTION OF DRAFT IN VIBRATOR FRAME

74 Steel is no better than cast iron in the matter of rusting, and possesses little advantage over brass in weight or cheapness. It is not much used for patterns.

75 Aluminum is not very well suited for the pattern itself, as it is hardly durable enough, and sand has a tendency to stick to it. It is, however, the best material for plates, and for vibrator frames. If made from any other material their weight would be almost prohibitive.

76 Wooden patterns are entirely unsuited for any but the roughest kind of repetition work. Even if the accuracy required is not very

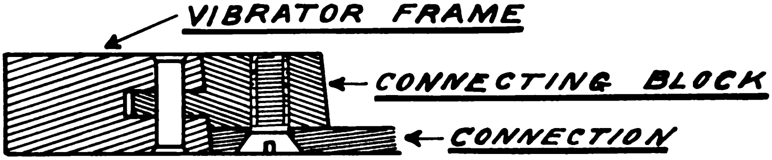
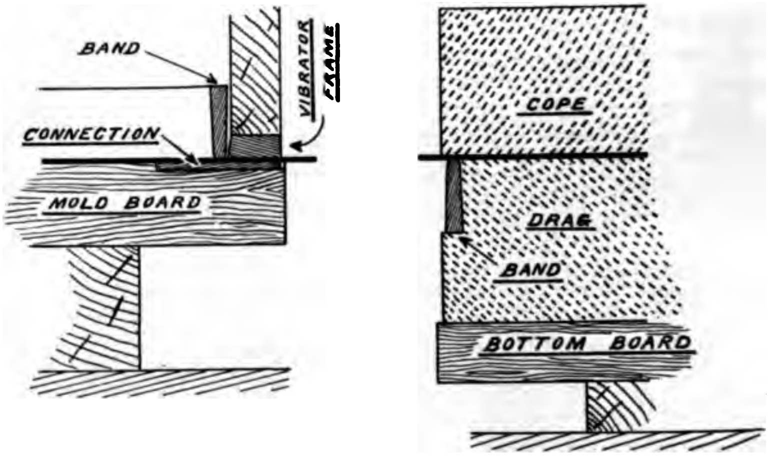


FIG. 34 SUPPORTING CONNECTION FROM PATTERN TO VIBRATOR FRAME

great, it will usually pay better to make metal patterns if a great number of castings is required.

77 For waxing metal patterns a liquid composed of bayberry wax cut with benzine until it is thin enough to apply with a brush, will be found very satisfactory. By painting with this liquid, a pattern can be waxed more quickly and evenly than by the usual process of

heating and rubbing with beeswax. The bayberry wax also gives a superior surface as it dries on in a thin hard coat, free from the stickiness which frequently gives trouble if ordinary beeswax is used. Bayberry wax is used to some extent in pharmacy, and can be obtained from any drug store.



Band testing on mold board   Band in position in the completed mold

FIG. 35 METHOD OF PROVIDING FOR A BAND IN THE DRAG

THE POINTS ON THE PATTERN AT WHICH SPECIAL ACCURACY IS REQUIRED

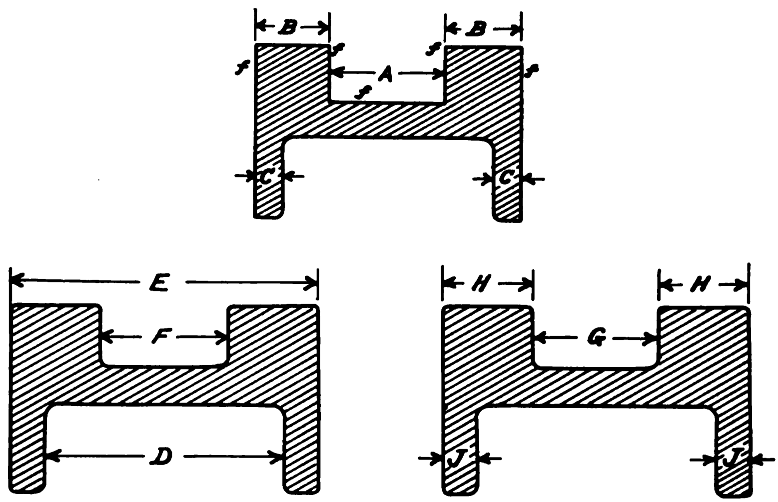
78 The importance of accuracy at different points on the pattern is indicated by the order followed in the list below:

- A Close clearance points at unmachined portions of the casting.
- B Locating points for the various machining operations.
- C Unmachined surfaces which should bear a fixed relation to each other or to machined portions of the casting.
- D All remaining unmachined portions of the casting.
- E Machined portions of the casting.

79 The machined portions are placed last in the list because a slight variation in the amount of finish can be tolerated. The accuracy of the pattern at the points where no finish is allowed is far more important, because the final dimensions of the casting depend entirely on the pattern. The locating points are also important, for if the castings from different patterns do not correspond at these points, variable results will be obtained from the machining operations.

80 Surfaces which are not machined, or which are used as locating points, should always be placed with reference to each other in such a way as to minimize the danger of incorrect spacing due to the possible cumulation of errors in measuring back and forth on the pattern.

81 Take for example a piece of the shape shown in Fig. 36. The surfaces marked *f* are to be machined, and the legs are to have a width *C* after machining. No special accuracy is needed for the distances *E* and *F*, as any slight variation will be corrected by the machining. On the other hand, if there are slight variations in *G* and *H* the errors might add up, and they might possibly be still further increased by slight errors in J, until the final width between the unfinished sur-



Correct method of dimensioning pattern

Incorrect method of dimensioning pattern

FIG. 36 ARRANGEMENT OF PATTERN DIMENSIONS

faces might become greater or less than the desired value *D*. But as the outside surfaces are machined to the fixed distance $A + 2B$, the thickness *C* can not possibly come right unless *D* is right, and a small percentage of error in *D* would cause a considerable error in the width *C*. Many a case in which the wall of metal left after machining is entirely too weak, or in which the cutters fail to clean up a boss, or in which they dig in after milling the boss away entirely is due to disregard of these facts.

82 In entering each dimension care should be taken to make the number of decimal places correspond to the degree of accuracy required, in accordance with the method described in the first part of this paper.

THE AMOUNT OF WORK TO BE EXPENDED ON THE PATTERN

83 The first item to be considered is the outlay on drawings, and there are really only two courses open to us. We can choose between making the drawings and not making them. We can avoid all unnecessary "frills" on them, but if they are made at all, they should be complete and reliable. They should be omitted only in very unimportant patterns, or in the case of patterns which fall into the very lowest grades of the repetition class.

84 In the actual construction of the patterns there is more opportunity for grading the work to suit the requirements, and for devising means of producing the pattern quickly and cheaply. In planning the method of executing the work, we should consider, first the degree of accuracy required, and second the expenditure which will give the most economical relation between investment and earning capacity. Careful attention to the varying degrees of accuracy, indicated on the drawings in the manner already referred to, will enable all unnecessary refinements to be avoided, and with a little ingenuity, labor saving short cuts can almost always be devised.

85 The form of the pattern should be studied to determine whether to build it up, cut it out of the solid, make it from a casting which is machined all over or from a casting machined only at certain points.

86 In the case of built up patterns it is often possible to use commercial brass rods which require no finish, or to use bars of any desired cross section which can be milled to shape accurately and cheaply by means of fly cutters, and then cut up as needed.

87 Many small patterns can be made from a solid bar of brass or cast iron more cheaply than from individual castings. If a pattern is of such a shape that it can best be produced from a casting, it may pay to make an accurately finished metal master pattern, castings from which can be finished up with the minimum amount of machining. Frequently the machining can be omitted altogether, the only finish required being a smoothing up with files and emery cloth. Or certain spots may be machined and the balance smoothed up. Of course, in making castings for this purpose care must be taken to avoid excessive rapping and to use a fine sand which will give the smoothest possible surface. To avoid errors due to hand molding it may also pay to mount the metal master pattern for temporary use on a molding machine.

88 The relation between working patterns, master patterns and grand master patterns can perhaps be brought out most clearly by

quoting the following rules which the author drew up some years ago, and which have been followed since that time with good results:

Rules

89 All patterns will be classed under one of the three following heads: *a* Working patterns. *b* Master patterns. *c* Grand master patterns.

Working patterns used for *Repetition work* shall be of metal, and in most cases mounted for use on the molding machines.

Working patterns used for *experimental work*, or for *jobbing work* shall be, in most cases, of wood. When practicable, they shall be arranged for temporary mounting for use on the molding machines.

Master patterns may be of wood or metal, according to circumstances. When the piece to be produced permits, the working patterns shall be made by smoothing up castings taken from a metal master pattern. In cases in which it is preferable to machine the working patterns, the master pattern usually shall be of wood.

Grand master patterns shall be of wood, or if made of metal shall be built up out of stock material. They shall be used in cases where it is necessary to obtain a casting out of which to make a metal master pattern.

Excepting in special cases, for which special provisions are made, the following general instructions shall be observed in making patterns and in making drawings for them.

METAL WORKING PATTERNS

Metal working patterns are the standard patterns for repetition work.

They are *made from drawings* showing the finished dimensions of the pattern itself. These drawings will be dimensioned to cover all necessary allowances for finish, shrinkage, and draft, and there will be no further allowance in making the pattern.

They are *made by* smoothing up castings obtained from the metal master pattern, or by machining castings obtained from the wooden master pattern, or by building up out of stock material.

They are *mounted* for use on the molding machines in accordance with the carding drawing.

They are *stamped* on the runner with the part number of the first piece produced from this casting. If one casting is machined to make several different pieces, the pattern will still have only one pattern number, which will be identical with the part number of the first piece produced. Each card will have a distinguishing mark, usually one dot on the first card, two on the second, etc., which will be placed so as to be visible in the casting even after it is machined. This mark will be in each pattern of the card, and alike in all patterns of any one card. Even if there is only one card, the distinguishing mark is to be put on it, as another card might be made later.

WOODEN WORKING PATTERNS

Wooden working patterns are the standard patterns for experimental or jobbing work.

They are *made from drawings* showing the finished dimensions of the piece, The pattern must, therefore, be made with allowance for single shrinkage, draft and finish, as noted on the drawing.

They are *mounted* for use on the molding machines whenever practicable.

They are *stamped* with the pattern number, which corresponds to the number of the finished piece. If one casting is machined to make several different pieces, the pattern will still have only one pattern number corresponding to the number of the first piece produced from it.

Particular attention is directed to the fact that patterns for runners fall under this heading and must comply with these requirements.

METAL MASTER PATTERNS

Metal master patterns are used to obtain castings suitable for use as working patterns after they have been smoothed up, or used in cases in which a wooden master pattern would not be durable enough.

They are *made from drawings* showing the finished dimensions of the metal master pattern itself. These drawings will be dimensioned to cover all necessary allowances for finish, shrinkage and draft, and there is to be no further allowances made when making the pattern.

They are *made of* castings obtained from the grand master pattern, or by building up out of stock material.

They are *mounted* temporarily for use on the molding machines to facilitate the obtaining of good castings.

They are *stamped* with the pattern number.

WOODEN MASTER PATTERNS

Wooden master patterns are used in cases in which the metal working pattern has to be machined.

They are *made from drawings* showing the finished dimensions of the metal working pattern. Allowance for single shrinkage, and an additional allowance for finish all over must be provided when making the pattern.

They are *mounted* temporarily for use on the molding machines when practicable.

They are *stamped* with the pattern number.

GRAND MASTER PATTERNS

Grand master patterns are needed only in cases in which a metal master pattern has to be made out of a casting.

They are *made from drawings* showing the finished dimensions of the *metal master pattern.* Allowance for single shrinkage and an additional allowance for finish, as marked on the drawing, must be provided when making the pattern.

They are *mounted* temporarily for use on the molding machines when practicable.

They are *stamped* with the pattern number.

90 The distinguishing mark on each pattern which is referred to in the rules above quoted is provided for the purpose of identifying the card from which a given casting was produced. This is a necessary feature if duplicate sets of patterns are run.

91 In discussing the flask sizes, reference has already been made to the use of a few patterns in a small flask for such patterns as would not warrant a larger pattern equipment. And even if a smaller flask is not practicable or desirable, it may often pay to make and card only a few patterns, leaving the balance of the mold unused, in preference to spending money in the tool room which the saving in the foundry might not offset in years.

92 When undertaking new work it is always a wise precaution to make and card only a part of the patterns, leaving the balance to be added later so as to facilitate the making of any changes or improvements which may suggest themselves in turning out the first few lots.

93 In the same way, if it is desirable to put through a limited number of castings from a new pattern to test out the tool equipment, much valuable time can often be saved by getting the castings as soon as a single pattern can be made and carded. The remaining patterns of the card can be added later.

94 If a portion of the mold is unused, do not spread out the patterns. Card the ones which are nearest to the sprue, and keep them close together to avoid waste of metal in the runner.

95 It is usually false economy to mount two or more different patterns on one card. Even if it seems that the proportion in which they will be used can be definitely fixed, for instance in the case of rights and lefts, unforeseen circumstances may arise at any time to upset the calculation. Repair orders may be heavier for one casting than for the other, or a batch of work from one casting may be spoiled and have to be scrapped, or the loss in the foundry or in the factory may be heavier for one than for the other. These and similar conditions may make it necessary to increase the output on one of the castings, and this is always troublesome and wasteful if different patterns are mounted on a single card.

96 One detail which it is necessary to watch is the tendency to "save time" by being careless in regard to the radii of fillets and rounds. A fillet is often difficult to produce, but that is no reason for shirking the work on it. Pattern makers should be provided with radius and fillet gages, and should be made to work to them.

97 The guide pins on each "plate," frame, etc., should be carefully fitted to a gage so as to ensure squareness and accurate spacing. A single adjustable gage with a series of doweled settings may be used to cover the entire range of flask sizes.

98 If careless work is permitted in the fitting of these pins, the foundry is driven to a more or less ineffectual tinkering of the flask

pins every time a pattern is changed. If proper precautions are taken to maintain the standard, all patterns and flasks of the same size will be perfectly interchangeable. A little graphite (not oil) should be used to lubricate the pins, and the fit should be as tight as is consistent with a smooth lift.

DISCUSSION

Mr. Robert Shirley I am surprised at the very small variation in pattern dimensions allowed by Mr. Berry, in some cases only 0.001 of an inch. It has been my experience that an operator on a machine, where the molds had to be rammed by hand, could make a very perceptible difference in the size of the finished castings by ramming the molds soft. The resulting casting, instead of shrinking, being considerably larger than the pattern.

2 A remiss engineer has caused us considerable trouble in this connection by dropping his air pressure, so that a power ramming machine intended to work under 80 pounds of air was actually working under 40, the results being soft molds, and castings considerably larger than the pattern. These are discrepancies which cannot be taken care of in either the drafting room or pattern shop.

Mr. E. H. Mumford Mr. Berry, owing probably to exceptional care and skill, as evidenced in this paper, took a set of very difficult patterns and absolutely new molding machines and installed them in a foundry where the labor conditions were especially adverse, and made a complete success of the installation.

2 Those of us who know how difficult a thing that is to do, and how many times the attempt meets with failure will appreciate what this paper of Mr. Berry's stands for.

3 The author speaks of the advantage of a small size of flask. The particular advantage of this outside of convenience in handling, is the elimination of the risk of sag. If the cope surface sags so that the two surfaces of the mold meet at or near the center they will surely creep out of match and cause all kind of queer distortions generally toward the outside edges of the mold joint.

4 It is stated that the flask must be deeper than the desired depth of the mold. That is true in ramming a bottom-board into the mold itself. It is not necessary, where a sand frame holding the excess of unrammed sand is placed over the flask. Mr. Berry illustrates what is to me a very interesting fact. I have found but one man in this country who has made the departure of putting a pattern in the cope,

and a pattern in the drag and bringing their corners together. The French practice, I understand has been for years to bring castings placed as these are in the mold into actual contact, so that the corners actually touch. It may seem paradoxical to some; and you will notice in the figure that Mr. Berry has carefully kept his casting about one-sixth of the spacing apart. If you could save this 16 per cent you would gain so much more room in your flask.

5 At the last foundry exhibition in Philadelphia, in May, a large number of castings was exhibited, made on the French molding machine in which the contact was absolute, and the castings after being poured and cooled adhered to one another until they were broken apart in the mill. The commercial advantage of putting castings edge to edge in a mold is very material.

6 In this paper there is no mention made of a solid cast match plate, and it is surprising to discover that there are foundrymen who have never seen a solid cast match plate made in its simplest form. It is not correct to say that you must have a joint surface in your plate that is susceptible of being machined or you must use "open carding." It is possible and it is current practice, to take the ordinary run of patterns and make a mold in the usual way, and then raise the cope the thickness of the plate you wish to make, closing the cope on a check against which the edges of the match plate will be run of desired shape and dimensions, forming what is virtually a fin in the casting the thickness of the match-plate desired. The only objection to the method is that, if the plate is heavy relative to the casting, the additional volume of the metal tends to produce a slightly rougher surface. There is a slight burring of the corners especially on the cope side of the plate, and, in match-plates, particularly those made of white metal or aluminum, or bronze, this may be eliminated by running a tool around the corners. There is an advantage in being able to do this tooling; by it you can make the mold joint firmer by taking metal out or burring down the surface at the corner.

7 This matter of the springing of the match board, or the bottom board, is one of great importance; but there are many other conditions beside the mere distribution of the pressure of the sand which tend to complicate the problem.

8 One of the cuts shows a gate in both parts of the mold. In our experience it is not good practice to put such a gate in, unless great care is taken to match it. As a rule, such care is not given and a slight mis-matching leads to an unsupported corner of sand, which is almost sure to wash and give trouble by carrying dirt into the molding.

9 In Par. 85, there is a subtle allusion to a very valuable fact;

namely, that it is not always machined or finely finished patterns which are the most perfect. There is no better surface for duplicating a casting than one which approximates that of the casting which you wish to produce, and excessive or over zealous finishing often loses a needed shape or thickness.

10 Not long ago I was in a foundry where the stripping plates were of solid iron (no babbitted edges), and the patterns in them were finished like parts of a gun lock. The manager remarked with pride, that there was nothing so cheap as money. Yet, in patterns which have cost so much, there is a strong temptation to save the pattern even after a careless finisher has cut too deep somewhere or rounded a corner which had better been left square.

Mr. H. M. Lane The Becker-Brainerd Company, of Hyde Park, Massachusetts, a couple of years ago, placed the entire planning of the work of foundry equipment in the hands of the engineering force. The time has come when engineers must appear in the foundry in very large numbers, because wherever a sufficient number of duplicate castings, requiring not only drawings but finished parts, are to be made, results cannot be predicted if any latitude be given the pattern maker.

2 This brings up an interesting point observed in the works at Ilion, which was the installation of a safety valve to limit the pressure in the holding mechanism of the machine.

3 It was further noticed that these people hold very closely to their gages. The men are held responsible for turning out castings to prescribed limits, and are not paid for them unless the castings correspond to these limits. The result is, that the men are careful because it is a matter of dollars and cents to them. Both of these factors are tending to produce very accurate work.

4 Another interesting observation was that when patterns intended for hand work are placed in the molding machine, the castings sometimes turn out too light and it is necessary to place bands on the outside.

The Author One of the contributors to the discussion questions the necessity for accurate pattern work in view of the accidental variations in the castings. He falls into the common error of failing to distinguish between avoidable and unavoidable variations. It is not true that all foundry work is necessarily inaccurate, but it is true that a uniform degree of accuracy is neither desirable nor possible.

2 Generally speaking machine molding gives more uniform results than hand molding, but in either case the practicable limits of accuracy depend on the size and shape of the casting, and may even vary considerably in different parts of the same casting.

3 For example a casting of the shape shown in Fig. 1 might warp as indicated in dotted lines, causing a considerable variation in the dimension A but only a slight variation in the dimension B.

4 Again in the case of a small casting which is to be held by the end C in a split chuck on a screw machine, it would be desirable and perfectly practicable to keep the dimension C within very close limits. If the card for this piece contained patterns varying among themselves by five or ten thousandths at this point, considerable trouble in chucking might result.

5 The up to date foundryman must train himself to recognize such differences in the conditions, and must always bear in mind that he must keep within close limits at some places, but that an equal degree

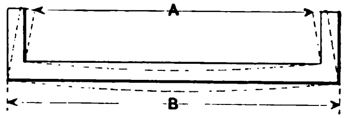


FIG. 1

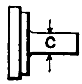


FIG. 2

ILLUSTRATIONS OF VARIATIONS IN CASTINGS

of refinement applied indiscriminately over the whole pattern would be entirely unjustifiable.

6 Variations due to carelessness in maintaining a suitable air pressure can surely not be classed as unavoidable. If an engineer were permitted to let his boiler pressure vary 50 per cent, no one would expect to get satisfactory results from the engine. Why then should we look for miracles in the foundry, and expect uniformity in the product with a variable air pressure? It is perfectly feasible to hold the pressure close enough for all ordinary molding, but in a few cases in which specially close work was called for, the writer adopted the expedient of connecting a relief valve to the cylinder of the molding machine. By using a valve large enough to relieve any excess pressure quickly, and by setting it for a pressure considerably lower than the normal, very uniform results were obtained.

7 One of the members suggests the use of a plate pattern in which the plate and patterns are cast in one piece. Such a pattern might be good enough for some classes of work. But shrinkage, to say nothing of a possible further reduction in size due to smoothing

up the surface, would prevent the pattern from being a close reproduction of the original. Heavy rapping may be used to correct the over-all dimensions, but unless the casting is very simple, the rapping will add extra metal where it is not needed. For really good work a machined pattern is an absolute necessity, and it is surprising how often casting inaccuracies, which are charged against the foundry, are really due to incorrect patterns.

No. 1177

SOME LIMITATIONS OF THE MOLDING MACHINE

By E. H. MUMFORD, PHILADELPHIA, PA.
Member of the Society

The recorded art of molding by machinery is far older than that of the steam engine, and there lacked only to-day's demand for multiple parts and the facilities for developing the art to have put it where it is now a hundred years ago. Thus, just as soon as a stripping plate was needed, it was "invented"—*more* than a hundred years ago and as soon as a foundryman felt the vibration of a pneumatic hammer, he used what we now call a "vibrator" to help draw a guided pattern.

2 About twenty years ago S. Jarvis Adams in Pittsburg jolt-rammed molds for pipe balls and wagon axle boxes; yet even today the modern jolt ramming machine at an exhibition attracts a crowd of foundrymen amazed at its novelty.

3 It was their long years of experience with the subtle and elusive behavior of green sand in the presence of melted metal in the secret intimacies of the closed mold that led Union molders some sad years since to scoff at molding machines and to foretell their doom unaided by the molder's skill. And molding machines have failed—machines of much ingenuity—heralded as labor savers because they did so many things done before by hand. These machines have failed because of too many opportunities for failure in a single enchained mechanism. Kipling's "Interdependence absolute" of McAndrew's idol engine is not for foundry use. Before the heartless biting cynicism of foundry ethics many a clever engineer has come to grief. Where melted iron rules and sand intrudes with every lubricant, refinements of machine design may not be much elaborated.

4 And so, though the Patent Office is filled with ingenious molding machines, most of them have failed, as the molder prophesied, while the art of machine molding has steadily progressed. It is still

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eliminating the machines which bring the sand in from the yard, temper it, riddle it and ram it, pass themselves their flasks, sand frames, sprue cutters and other accessories, draw their patterns, deliver the finished molds and have only to be restrained from setting the cores.

5 It is assimilating good simple efficient machines content to do a few things well.

6 It is not speed of production of blocks of sand which look like molds and which in the halcyon days of "demonstrated" machines often passed as such and sold the machine even while the "demonstrator" walked around upon them, which in 1907 proves the machine. The present day molding machine must take what the foundry gives it and turn back what the foundry wants,—molds in quantity and of quality excelling in economy of production the product of hand labor in *castings* or it gets no welcome there.

7 But there is another reason for the markedly gradual and cautious development of the molding machine. It is the infinity of shapes and kinds of patterns around which green sand must be rammed with uniformity of mold surface, and the necessity of arranging some more or less universal method of withdrawing these patterns from the rammed sand without in the least degree displacing it.

8 In other fields it has paid the most brilliant mechanicians of the age to develop elaborate and expensive machines for doing one kind of work always. Our machines for making cigarrettes, envelopes and paper bags are fair examples. For molding machines there is no one casting of a certain size and shape in required quantity comparable with cigarettes, etc. At the speed of the envelope machine, a few molding machines would supply the demand of the entire country and in any one shop a single machine would run far ahead of its market in a day or a week or a month, and then waste its shop room.

9 Another limitation to the exploitation of molding machines to make molds as bricks are made lies in the fact that these machines, unlike those for making bricks, do not finish their work. Sand and flasks must be supplied to the machine and castings must be poured and cooled and shaken out. It would not be difficult to design a machine which would mold for example, 200 shoes per hour, and such machines have, in fact, been built. Each machine, however, would call for 5000 pounds of sand and as many pounds of flasks to be delivered to it and carried away from it again every hour. Even then the molds are in halves and without cores set; 200 cores must be set and 100 copes closed on every hour. To keep the "floor" from gaining on the foundry, 5000 pounds of hot metal must be poured from

double hand ladles every hour which work would keep from four to six men busy pouring and shifting weights. As many more men would be required to shake out and remove hot castings, and at least two more to get the flasks off of the floor again. Only a little foundry experience will prove that this situation is impossible. The elaborate foundry structures for dropping both sand and castings through the floor still leave the labor of setting cores, handling and closing molds, pouring and shaking out to be performed. In fact, we are far from the realization of a molding machine which will turn out castings, as do the type casting machines and all machines which cast mildly hot metal in chills, and which may not be called molding machines as their molds are already prepared. The mold which melted iron will not destroy and which will not exaggerate unequal cooling of the casting surface, with resulting evils, is no nearer our commercial use than is the Philosopher's Stone and, until it is, the molding machine, delivering only incomplete sand molds, will still invoke the genius of the designers who know where to limit its functions, and the ignorance of those who do not.

LIMITATIONS OF MACHINE FUNCTIONS

Ramming

SOFT DEEP SAND

9 Sand will flow only slightly under pressure, hence pressure and blow ramming machines fail to reach deep parts because shallower parts absorb the pressure.

10 Sand, especially in pressure ramming, is subjected to great friction in its movement down the sides of patterns and flasks—hence even directly vertical pressure over deep parts does not ram them down all the way.

RAM OFFS

11 After sand is partially set in a mold, by pressure or other means, it has taken the shape of the pattern, and if it is moved, it carries this pattern shape—as of a corner—with it. Thus a blow of a hand rammer at one side of the sand compressed by a previous blow, shifts that partially rammed sand aside, and generally away from the pattern.

12 In jolt-ramming machines a peculiar ram off effect occurs at every upwardly convex corner of a pattern. This is due to previous jolting having set the sand over the pattern at the corner,

with the result that little of it can follow out and down past the corner to take the place of the deeper sand which the later blows of the jolting cause to settle down the more or less vertical sides of the pattern. The result is a zone of soft sand just under the pattern corner.

13 Still another failure in ramming, in the nature of a ram off, occurs in what is coming to be known as the "gravity" machine, though it is no more entitled to the term than the jolt-ramming type, gravity alone being employed in both machines. Allusion has been made to the upward looking convex corner of the pattern around which it is hard to get the sand to flow. In the jolt-ramming machine the sand is placed in pockets, and along the pattern sides prior to ramming, while the sand in the "gravity" machine falling in bats, tends to shed off the corner more than sand previously placed around it; and this has led to constant failure in the past in this very old method of ramming. Moreover the sand, falling from a fixed height, tends to ram all parts of the mold equally hard—which has the especially undesirable effect of making copes as hard as drags. In fact it seems worth mentioning here that what is called "uniform ramming" is not a desirable feature in molding machines. The more sand density can be varied the better.

14 In vibrator frame machines, called such, though the same term may be applied to any machine using an undivided pattern with extensions from the patterns to guides outside the mold, the effect of ram-off is commonly produced by springing of the unsupported pattern during ramming—it being immaterial whether the movement be in the sand or the pattern.

BARRED FLASKS

15 Flask bars have been a limitation more or less serious in all molding machines. Taking all kinds of bars into consideration, including those which spring under jolt or pressure ramming, there are none which do not give trouble, or cause loss of time, if we except the so called "floating bars," and even these must be nicely proportioned to depth of sand, etc.

16 Pressure-ramming machines must employ special ramming blocks cut away to clear bars.

17 Jolt-ramming machines require that the bars shall be very thin, and yet not spring, for if a bar shakes off the contact of the sand and the frictional bond between the sand and the bar is destroyed, the bar merely aggravates the tendency of the sand to drop from the flask, by cutting it into channels and unsupported blocks.

18 The writer knows of only one bar that will hold the general mass of sand after the sand has actually separated from its under edge. It is one which has been designed specially for jolt-ramming and tested with complete success and it permits the sand to settle away from it in the cope while keeping the mold from "coping," as the runner fills up; for it holds the sand down as well as up.

19 The floating bar, whose action is ideal, if its descent into the sand under it is properly controlled, is an element in what is known as bottom-ramming, and the action is the same whether the bar only, or the bar and the flask which holds it, moves toward the pattern in ramming.

20 This is the only form of flask bar which is not even theoretically, a limitation to ramming by machine.

RAMMING PATTERNS DOWN OR SAND UP

21 It is impossible to ram sand up into an inverted pattern, as is required in making a drag mold without rolling. The pattern must first be filled and surrounded with sand. Rathbone did this first in 1905. He was using a blow-ramming machine, with an inverted drag pattern on a match board for producing multiple molds, and found that the projection of the unrammed sand against the pattern an instant before ramming—a result incidental to the apparatus he used,—accomplished what had not been done before.

MACHINE LIMITATIONS IN PATTERN DRAWING

MISMATCH

22 It is assumed that patterns and flask pins are accurately fitted; mismatch is caused by the following four conditions: *a* cope and drag parts of the pattern on separate carriers—nothing but a miracle can insure accurate match, for all the errors due to misfits of the dowels, etc., enter in, as they do not when the same rigid piece carries both parts; *b* the pattern carrier separated from the part of the machine containing the flask pins. An apparent exception to this is the ordinary stripping plate machine, when patterns are new. In this case, the pattern may move out of match, but the new stripping plate with flask pins in it in sliding over them forces them into place. It goes without saying that the edges of both the stripping plate and the pattern suffer in consequence. *c* Lack of support of joint surface during pattern drawing downward causes sagging of joint.

23 If from any cause the two joint surfaces of a mold are not perfectly flat, or, if not flat, perfectly inversely similar, such a joint will "creep" out of match in closing. For this reason, mainly, better matched molds are obtained from stripping plates, which support the joint during pattern drawing.

24 In the first use of vibrators on machines, the slight lateral freedom of the pattern carrier necessary with reference to the mold was secured by the proper freedom of a match plate on the flask pins. In the endeavor to improve vibrator action, the pattern carrier was separated from the part containing the flask pins. The idea was that the agitation and dropping of the sand while drawing patterns *down* would be thus avoided. While this was, in a measure, accomplished, the clearances thus introduced allowed the patterns to shift out of match during ramming, and led to the introduction of untrustworthy automatic locking devices dependent upon springs.

25 *d* Bottom boards and match boards springing under ramming produce the amorphous joints last referred to by causing convex drag joints, if the ends of boards have sprung into molds, and concave drag joints if the centers have sprung in. A prolific source of this failure in machines is the use of skids instead of flat tables in pressure-ramming machines. For example, with 2½ inch skids, placed 10 inches apart, the center of the board of a mold 14 inches long will be sprung in, producing a concave drag joint; while the ends of the board of a mold, 28 inches long, will be sprung in and a convex drag joint result.

BROKEN CORNERS

26 Stripping plates know no such failures, for their essential function, as indicated by their French name "*peignes*"—combs, is to comb the sand along the edges of the pattern. But, in those machines which employ vibrators to start the edges of sand, three things are necessary: *a* Clean and well drafted edges of the patterns. *b* Absolutely straight movement of these edges relatively to the sand, or *vice versa*. *c* Flasks undistorted by clamping or otherwise.

27 In the matter of clean joint edges, an interesting detail has within the last few years been developed. Split patterns on match plates are frequently hollowed out to save weight and metal, and all patterns have more or less air space between them and the plates. Mr. Walker, at Erie, found that at the moment of ramming by pressure, the air under the patterns is compressed to the 30 to 50 pounds pressure of the mold, and that, to effect this compression, the very damp air in the unrammed sand is forced under the pattern—then,

immediately, when the pressure is taken off the sand, this imprisoned damp air issues from this hollow under the edges of the patterns next to the plate. This constant breathing in and out of wet air causes wet corners to which the sand adheres.

28 This has led Mr. Walker to adopt the plan of sweating his patterns on a tinned plate. The little fillets of solder which run up along the pattern edges help the pattern draft very materially.

29 The slightest touch of a pattern on the sand corner that it is leaving takes at least a little of that corner with it. An illustration of this has been the absolute failure of what is known as the vibrator frame and of vibrated solid patterns on chain link and saddlery hardware. The hand molder, rapping his pattern through the cope into the closed joint of his mold and then, with practised hand setting his patterns in the exact center of the enlarged sand chamber he has formed, lifts his cope clear and clean, while the vibrator moves the pattern very little; the guide on the flask pins, though true, is vitiated by the rocking in hand lifting, the sand corners are sure to touch somewhere, and just there the sand is either torn up or knocked down, depending upon whether the pattern is drawn up or down.

UNTRUE DRAFT

30 I have just mentioned the rocking of a mold or pattern by hand as fatal to clean draft. Any divergence from a line of draft normal to the joint surface of the mold, or a line predetermined, is equivalent to vitiating the "draft" given the pattern by its maker and setting up a back draft. Yet these conditions arise in what are known as rock-over machines, which draw their patterns from molds lying on tilting bottom boards.

FLASKS SPRUNG

31 Hand-rammed rock-over machines retain a weakness which every experienced molder would avoid. The flask—often a very shallow wooden flask— is edge-clamped to the pattern board. The springing and subsequent recovery of the flask deform the joint of the mold unless the hand molders' method of wedging the joint is adopted. Mr. Pridmore foresaw this difficulty when he first began to build rock-over machines years ago, and patented clamps which prevent the springing of the flask.

32 It is an axiom in machine molding that all pattern draft must be taken from the mold joint, and that this joint must be maintained without deformation until the mold is closed.

SIZES AND SHAPES OF MOLDS

33 Molding machines are now in a position to say to the trade that the mere size of a mold is no reason for not making it by machinery. This is very evident in the case of hand-ramming machines where the problem of furnishing from 15 to 100 pounds ramming pressure to every square inch of area is not encountered, and in the most widely known hand machines, where the ends of the frames which carry the stripping plates are left open, any length of flask within the width capacity of the machine may be accommodated, provided the length is not sufficient to cause too great an overhang.

34 Until this year, America has not known familiarly a complete molding machine that would handle for both ramming and drawing patterns any size or shape of mold for which it had ramming capacity. Consider for a moment what it has meant to the introduction of molding machines that a power machine has been used for, at most, three or four sizes of flasks, the only latitude being in width, and this limited to a narrow maximum.

35 In lathes, many diameters and lengths of work are handled. In planers, variations in all three dimensions are provided for. Yet, in molding machines, where the sizes of molds are as various as the sizes of the castings which go to a machine shop, designers in this country have contented themselves with practically a separate machine for each size of flask.

36 To illustrate how easily satisfied the foundry trade is, let me say that for years several machines of different sizes have been sold to foundries in which a single size, and often a single machine, would have answered the purpose.

37 And the only arguments advanced therefor have been: *a* It will not do to have too large a top on a machine, as the projection beyond the flask catches sand. *b* The flask pins in the machine require that the pin dimension of the flasks should be constant.

38 Our technical press has lately been filled with descriptions of a French molding machine and its equally interesting pattern equipment, which is without any question the most brilliant work in machine molding in a hundred years of development. The able Frenchmen who have evolved this mechanism have christened it "Universal," with an intensity of meaning characteristic of the deep thought which has produced it.

39 As to the machine itself, what has it done? It has emasculated the potent arguments which have filled our foundries with polyglot machines, since no part of the French machine projects

beyond the flask to catch sand, no matter what the size or shape of the flask and the flask pins *are not in* the French machine.

40 It is not necessary here to describe this remarkable machine and its fit companions, the Plaques Modêles and Clichés Tables which promise to reduce our molding machine metal pattern costs from 50 to 90 per cent. Very complete descriptive matter from one of the inventors, Mr. Ronceray, has been published in the "American Machinist" and elsewhere, and later on, a full functional analysis of these machines may well add to the value of our Transactions.

41 The writer will enumerate the limitations of the molding machine as known in America to-day, which are eliminated by the new machine molding of France.

Ramming

SOFT DEEP SAND

42 All the French machines may be fitted at a trivial cost with *Double Serrage*—an appliance for double-ramming. This is simply an auxiliary plunger under the mold table of the machine, set quickly to stop gage, to which are attached what we call, in the United States "stools." While the main ramming pressure is on, these stools, which have receded to allow a given amount of sand to enter the pocket or cavity, are run against the stop gage and the soft sand is made just hard enough. This procedure is general from Tupper grate bars to deep and intricate green sand cores in automobile castings.

RAM OFFS

43 Only a single application of pressure is made, and deep vertical sides are rammed from the opposite direction so that no "ram-off" can occur.

MISMATCH

44 As the flask pins are not in the machine,—though they are drawn by the machine,—the match is made and maintained in the foundry, so that, with full responsibility, the foundry may also have credit for matches more perfect than heretofore.

BROKEN CORNERS

45 As stripping plate patterns made by the French process are as cheap as the various forms of vibrated patterns heretofore known

in America, it becomes much more practicable to adopt stripping plates.

46 Broken corners, such as have to be considered in vibrated patterns, are unknown to stripping plates. In fact, except for the cost of the latter, there would never have been use for vibrators in connection with molding except as adjuncts to stripping plates. This is even true of patterns drawn *up*, especially, as in the inverting French machines, the stripping plates or stools follow the sand down automatically.

UNTRUE DRAFT

47 There can hardly be truer pattern draft than that guided by the same plunger which has done the ramming, as is the case in all the French machines of the rotary or inverting type. The only necessary precedent is that the ramming, or bottom board which has been forced into the flask, if such an one is used, shall have an even seat when the mold which is being lowered on the inverted ramming plunger is leaving the pattern. The slightest difficulty from this source is easily removed by three-point bearings.

48 In the French machines of the fixed type, the pattern draft datum is taken from the mold joint itself, inasmuch as the columns which raise the stripping plate and the half mold upon it have adjustable tops which are set at the start to conform to the exact surface of the mold.

FLASKS SPRUNG

49 Since no clamps are used, there can be no springing of flasks from this cause. Furthermore, I would here mention an innovation illustrating the national differences in everyday practice in the molding methods of two countries, in even these latter days of constant interchange of ideas.

50 The French use round flasks as commonly as we do square ones. They use snap flasks hardly at all, and yet they obtain from solid flasks what we know only as snap molds.

51 When it is stated that 220, 21-inch round "snap" molds are produced in a day by two men from "solid" flasks, I know that many will ask "How?"

52 The molds are made as molds in 21-inch round flasks would ordinarily be made; except that very thin "binders," hoops of steel only $\frac{1}{32}$ inch thick, are employed. The drag mold is then set upon a plate on the round table carried by an assembling machine, the table and plate being a little smaller than the inside of the flask. This plate serves as a bottom board. The cope mold is placed above the drag,

over long pins common to both parts, so that the match is absolute. The cope flask being locked so that it cannot rise, the plunger rising against the drag carries it up to the cope, closing the joint, and then the continued ascent of the plunger forces the sand bodily up out of both flasks, and we have the strongest shape possible of a snap mold held by binders—a cylindrical one.

53 Thus by methods radically new we are introduced to a system of machine molding which has profited by a study of the limitations of previous machines. Not all of the limitations I have named nor others not mentioned, because so numerous, have yet been surmounted; but Paris at present holds the prize for the greatest advance.

54 So complicated and so varied are the demands upon the foundry molding machines, that, unattractive as the hot, dusty foundry is to engineers, I suggest that to-day there is no more promising realm of thought to attract the genius of the machine designer who has had the opportunity to learn by hard experience what a molding machine can, and what it absolutely cannot do.

DISCUSSION

MR. RONCERAY[1] Mr. Mumford mentioned exceptional cases where it might be necessary to provide for double-ramming, that is, ramming deep pockets from the mold face independently, and his presentation of the case, according to my experience, is characteristic of the condition of machine molding in this country. In this country the power pressing molding machine has been applied especially to shallow castings. It has been quite a different proposition on the other side of the ocean, governed largely I suppose, by the peculiar requirements of the trade. There is very little repetition work there, while on the contrary there is considerable of it here. We have perhaps more exacting conditions to meet; that is why no doubt, it has been found necessary to ram deep parts in the mold; and this is the reason for the presence of what we call "double-ramming."

2 It will be understood that after the mold has been rammed from the top, the stool is given additional pressure from the bottom. This method is used for special cases. It is not for general ramming around deep patterns.

3 This gives me occasion to describe a new molding machine, illustrated in Fig. 1 and Fig. 2. Take for instance, patterns shown

[1] The Universal System of Machine Molding, Philadelphia, Pa.

in Fig. 1, for a projectile, which shows the usual shape. It is expedient to have several projectiles in the mold, but only two are shown which will be sufficient for the demonstration. It is well known the difficulty in trying to ram sand around too small pieces like those described. The problem has been solved in this way; the patterns have been made longer than necessary for the mold itself,

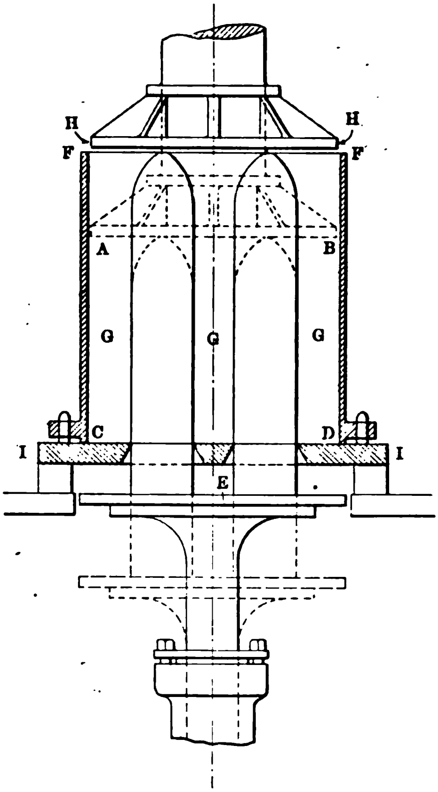


FIG. 1 A PATTERN FOR A PROJECTILE

ABCD as shown, and they are mounted on a plate *E* on a piston which has a vertical motion. Place sand in the flask, and sand frame up to the level *FF*, the sand to be rammed in, as on an ordinary molding machine, except that in an ordinary machine it is evident the sand would not be rammed at *GGG*, even if the patterns were fixed at the position shown by the dotted lines, and sand rammed over them, the friction of the sand would interfere with the ramming. As shown in the sketch, the descent of the ramming plate *HH* carries patterns and sand down together until checked at the surface *AB* by an adjustable stop and a perfectly rammed cheek is made. When sand is rammed over the patterns, and the patterns are pushed down through the stripping plate *II* by other means than actual contact with the patterns themselves, so leaving sand over them, a complete half mold, instead of a cheek, is formed. This method has been tried on difficult work, and it is a very effective way to ram deep sand without hand work.

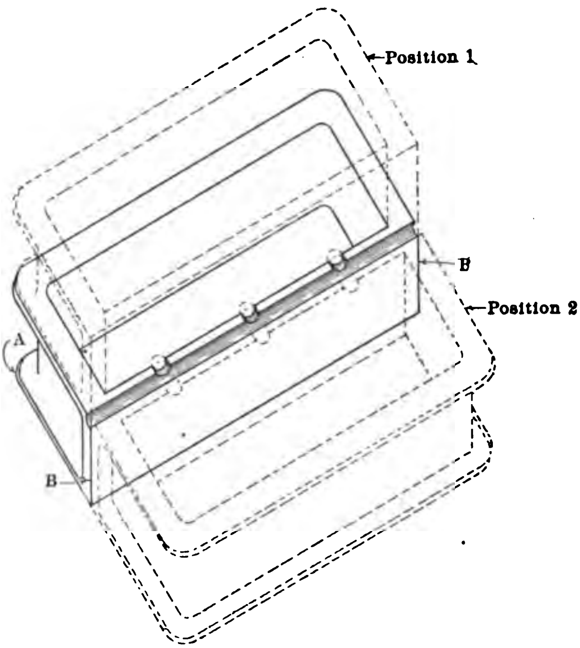


FIG. 2 A SPECIAL SET OF PATTERN-MAKING FLASKS

4 The author mentions that the production of stripping plates requires great accuracy. There are stripping plates on which the cope and the drag part of the pattern are put along side of each other.

5 Great accuracy is obtained by a special set of pattern making flasks, as shown in Fig. 2.

6 *A* is one-half of an ordinary flask. cut in the middle, and closed by a fourth side put on at *BB* and finished with great accuracy. What Mr. Mumford has called a foundry jig comprises two of these half flasks, and a single cope flask.

7 Placing the second half of the flask over the first, and ramming it up as a cope mold on any patterns lying in the joint, the planed

sides being held accurately in the same plane by bolts and dowels, in position 1, and then lifting this cope and rolling it back into position 2, we obtain a duplex drag mold in which every part of a mold in one half is absolutely opposite every homologous part of the mold in the other.

8 Over this duplex drag a one-piece cope mold, which has been separately rammed up, is placed upon a frame which constitutes a special check of small depth, and the pattern plate run in this three part mold will have the reversing principle embodied in it by virtue of its method of manufacture.

9 Reversing stripping plates are made in the same way except that they are made in the joint itself without the cheek frame.

Mr. Harris Tabor In any broad discussion of machine molding the view points and interests of several different individuals must be constantly considered, i.e., the manufacturer of the article to be molded, the designer of this article, the pattern maker, the molder the designer of the molding machine and lastly the vender of them.

2 As the designer of the American types of molding machines which are criticised in Mr. Mumford's paper, two questions suggest themselves as I read it. First, are the limitations mentioned really those which are met in American practice; and second, admitting all the statements in regard to the Universal machine, the French type, contained in the eulogy with which the paper closes, will not its limitations bar it out for even consideration on 90 per cent of work which under favorable circumstances might be done on machines?

3 The molding machine proper does not set the limit to machine molding. The limitations are generally governed by commercial and foundry conditions and the disposition on the part of the foundry management. In this country frequent changes of design constitute a serious limitation to machine molding, and he is a wise man who can determine how long a pattern can be used before it becomes obsolete. In Europe, where patterns are subject to fewer changes, and the product from the hand molder is so much smaller per man, molding on expensive machines can be made profitable.

4 The market in this country today comes largely from the jobbing foundry which has very little repetition work, and this calls for the simplest form of machine possible—inexpensive and with a comparatively low cost for pattern installation. It is this demand that has made so popular the hand ramming marginally-hinged or rock-over machine with a straight draft independent of the rock-over movement.

5 With certain kinds of patterns "ram-offs" are always possible with both power and hand ramming but in practice these rarely occur with good management. The type of machine most likely to produce "ram-offs" is that which packs the sand with a series of blows and is commonly styled the "power rammer." Nevertheless the largest machine molding plant in this country, and probably in the world, uses this type of machine exclusively, and has done so successfully for 20 years. This indicates that in one place at least the "ram-off" has no terrors. What may pass for a "ram-off" with the uninitiated or the semi-initiated, is often caused by the springing of too light a flask. The real limitation of power ramming flasks with fixed bars lies in the difficulty of filling the flask evenly. When this is done with the aid of a shovel the operator is apt to give more velocity to the sand going in to some compartments than others, and the result is an uneven mass which calls for more or less hand work before power ramming is applied.

6 If the barred flask be large in area, it is better and in the interest of economy to use it on the simpler form of hand ramming machine.

7 Flask bars have a twofold mission; first, to serve as a support for carrying the sand and to prevent coping when the mold is poured; second, to strengthen the walls of the flask. These two functions insist that when the flasks are large the bars be firmly attached to the walls.

8 Floating or loose bars should not be used in large flasks, unless the bar ends have a sliding connection with the flask walls to prevent the latter from springing under the pressure of ramming. Often under these conditions the friction of the bars in their guides may be great enough to prevent a portion of the downward movement of the bars which is so essential with this system of ramming.

9 With smaller flasks, however, these bars may be grouped in one piece producing an effect like reënforced concrete and used to excellent advantage. In the early molding machine days the writer was so enthusiastic over what is now commonly known as the floating bar that he took out a broad patent covering this feature. This patent, now expired, anticipated all that is now being done with this form of flask bar.

10 Assuming that patterns and flask pins are accurately fitted, all molding machines on the American market today will produce castings with little trace of the flask joint. The power molding machines with which we are familiar have marked similarities in their pattern drawing mechanism.

11 When a sag in the mold joint occurs, due to drawing the pattern

on the vibrator type of machine, it is advisable to introduce a simple stool at some point in the pattern plate to prevent this; but where a sag, due to the weight of the sand, occurs, the only remedy is to use a deeper flask or introduce bars.

12 The Alley & McClellan molding machine, used exclusively in this country by the Westinghouse Air Brake Company for 20 years, is, like the French Universal machine, hydraulic, and in both cases the downward movement of the ram serves as a guide for pattern drawing.

13 The suggestion that the skids, used instead of a flat table in pressure ramming, are responsible for mismatch is hardly borne out by experience. Probably one-half of the molding machines in this country are of this type. Yet they all seem to be doing good work. This type of machine has two cross bars on which the cleats of the bottom board rest during ramming. The pressure applied to these machines is sometimes produced by compressed air but more generally by the weight of the workman through a hand lever.

14 In this construction the crank is used in such a way that it passes into the idle arc at the time of the maximum pressure. It does not matter how the pressure is applied, so long as it is sufficient to ram the mold properly. This type of machine is ordinarily what might be termed a snap flask machine, and is rarely used on anything but bench work. It is possible, of course, to use flasks so long that the overhanging ends of the bottom boards and the space between the cleats may spring to such an extent that a mismatch or broken mold follows. Such cases, however, simply indicate bad practice in the use of the machines, and rarely occur. Our finest castings—and showing absolutely no trace of the flask joint—are made on this type of machine. The excellent paper by Mr. E. H. Berry read at the Annual meeting, on "Patterns for Repetition Work" illustrates the advantages of this system of molding.

15 It is a mistake to insist that stripping plates never produce broken corners. With the stripping plate method, it is very easy to "comb" the sand along the outer edge of the pattern, and the inner edges where such exist, may also be treated in the same manner. These edges will always show clean and fair in the mold. But in cases where patterns have projecting points some distance from the stripped edge, there is always a possibility of broken corners where the stripping plate only is depended upon. The vibrator is not so effective on patterns with long, straight draft as the stripping plate, but on the other hand it is decidedly more efficient in drawing from the sand those points which are beyond the reach of the stripping

plate. Both methods of pattern drawing are excellent, and for each there is a large field.

16 The great advantages of this vibratory feature of American design have been discussed quite fully by Mr. Mumford in his paper, "Machine Molding without Stripping Plates" read before the New York Meeting some years ago and in articles appearing from time to time since then in the technical press describing various types of both power and hand ramming machines.

17 Untrue draft always means broken molds, and should never be permitted in any type of molding machine. No molding machine builder in this or any other country would knowingly tolerate such a fatal defect in a machine. It is true, as suggested, that untrue draft may result in a flask improperly leveled on the type of machine known as the rock-over. The author of the paper under discussion might have added to his criticism that the builders of the straight draft rock-over machine supply a leveling device which automatically adjusts itself to any irregularity in the flask, thus insuring perfect draft.

18 The round flask may be popular in Europe. It can have no place in this country except for pulleys, gears, and other patterns of similar shape. The American founder insists first, last, and all the time, upon the minimum amount of sand to be handled. The only advantage the round flask possesses for general work is that it may be made much lighter without danger of its springing under the pressure of ramming. This advantage is more than offset by the greater amount of sand required, and its general unfitness for the average commercial pattern. At least 90 per cent of the castings made in this country call for a square or rectangular flask. In some lines of foundry work, such as valves and fittings, there are two standard lengths of flasks—16 and 18 in. The width of these flasks varies from 9 to 14 in. These sizes have been determined for small fittings after countless experiments and years of experience. It is doubtful if any other shapes would yield as much in the way of castings per ton of sand. These flasks are sometimes of iron; but more commonly snap flasks are employed. When the latter practice is followed, a retaining band, as described by Mr. Mumford, is used, thus making the mold practically as strong for pouring as when made in a heavier iron flask. This method of using a band is shown in Mr. Berry's paper to which reference has previously been made.

19 There are various ways of dealing with deep bodies of sand which lie between the walls of the flask and often between the patterns. In some cases the operator would invert his shovel, use its

handle for a ram, and with a few strokes pack the sand at these points, leaving the balance to be done by the machine. In many cases a slight pressure of the hand only is necessary. The ramming head may also be cut out boldly over the high parts of the patterns, thus relieving the pressure at these points. In many cases the skilled operator will scoop out with his hand a portion of the sand overlying the high parts of the pattern, and thus give relief. All the above methods are simple, inexpensive, and probably quite as effective as the more complicated and expensive method of ramming these points from below.

20 The limitations of machine molding are very few, if the machine gets into the proper hands. If one could go through the plant at Ilion, in charge of Mr. Berry, he would marvel at the work done on molding machines. After investigating that plant thoroughly, we think he would agree with the writer in feeling that Mr. Berry has given us one of the best pieces of molding machine engineering in this country. The limitations of the molding machine are largely in the hands of the men who furnish the tools, equipment and patterns. Fortunately for the foundry trade, we are getting a class of men expert in pattern making, and in adapting patterns to molding machines. In the present advanced stage of molding machine design in this country it is to these men we must look rather than to the molding machine builder for the removal of molding machine limitations.

21 Since this paper was presented, arrangements have been completed by which the right to manufacture the Universal machine in this country has been acquired by the E. H. Mumford Company. It will be interesting to see in what measure the points of strength claimed for it will assist in solving the problems of the American foundrymen and to what extent it will lead to a more general use of machines for molding purposes.

The Author Mr. Berry speaks of the difficulties on the bottom board. By all means use cleats. A bottom board or a mold board is much freer on a machine to push through the sand if there are cleats under it. It is well known that no really first class work, of even moderate depth, can be secured from a molding machine without some form of checking of the edges. In some of the fastest molding I know of it is done, but it is best to do it by putting edges on the boards. When a board is tongued on a drag mold and the coat is rammed upon it, where there has always been some sand checking, a very large percentage of the pressure of the machine falls on those previously packed gores, and that is a very heavy load on a bottom board, unless it is battened on the bottom to meet that pressure.

2 I think a jarring machine has fewer limitations, perhaps, as to size, excepting the question of impact and solidity of foundation; certainly as to depth there seems to be little limitation. Machines are used for molds of considerable size, for car wheels, steel wheel centers and things of that sort. I know that in the Chapman works they are jar ramming some large valve bodies of 18 in. and that is certainly a very large proportion, and Mr. Knickerbocker tells me that he has been doing it most successfully.

3 I notice that Mr. Tabor states that I criticize the types of machines he designed. Reference to my paper will show that my statements of machine limitations as I see them apply as freely to machines of my own design as to those of his and others; they have to do with machine molding practice more than a century old and are not by any means exclusively American.

4 The fact that Mr. Tabor does not name a single defect of the many which must lurk in any machine that is unfit for "even consideration" in practically all of its work invalidates the criticism. To imply that a machine is beyond the pale even of consideration for all but 10 per cent of its work, and to give no reason for this, is to infer without proof that the machine is a commercial failure and mechanically unfit for use. No man's machine should be so broadly condemned before an engineering society without any reason being given.

5 Mr. Tabor refers to the Westinghouse machines as hydraulic like the machines of Ph. Bonvillain and E. Ronceray and makes the irrelevant comment that the patterns are drawn by the motion of the ramming plunger.

6 There is absolutely no resemblance between the two machines of both of which it is true, as in many machines, that ramming plungers have some part in drawing patterns and the evident comparison of the French machine of new and broadly patented design with the Scotch machines "used ——for twenty years" is, at best, unscientific. The statement that "in both cases the downward movement of the ramming plunger serves as a guide in pattern drawing" does not tell the whole story. The rest of it is that the plunger he refers to in the French machine is the ramming plunger of the power-ramming, power-clamping, power-rolling and power-pattern-drawing machine, a plunger with a three fold function, doing its ramming, clamping its bottom board to its mold and drawing perfectly without a "levelling device."

7 Mr. Tabor attaches much more importance than I did to "ram-offs." He knows they exist exactly as I stated and the blunders of beginners are not valuable. Such "ram-offs" as I described in Par. 11, 12 and 13, cannot possibly be caused by flasks springing.

8 Mr. Tabor says "The real limitations of power-ramming flasks with fixed bars is due to the difficulty of filling the flask evenly." Of course it is well known that careless filling with a shovel of any flask, barred or unbarred, gives trouble. But this is only a little thing among bar difficulties. This suggestion leads me to add that when I can, by use of a double screened "loose-ring" riddle, fill flasks through No. 4 mesh, No. 14 wire, at the rate of 1 cu. ft. of tempered sand every 6 seconds, I do not use the shovel at all.

9 The use of gaggers, floating grids and frames carrying ramming spikes in the very old hydraulic machines for pulleys and such like makes it impossible for any one now to claim priority in such ideas. I patented a telescopic flask for the effect of floating bars in the cope flasks for tunnel plates some years since. Mr. Tabor speaks of his floating bar patent having been taken out "in the early molding machine days." Mr. Tabor is, relatively speaking, a very recent, though an able worker in molding machines. Molding machines were nearly ninety years old in both England and Germany before Mr. Tabor took his first patent.

10 Mr. Tabor says "Assuming that patterns and flask pins are accurately fitted, all molding machines on the American market today will produce castings with little trace of the flask joint."

11 I must call attention especially to Par. 24, of my paper which referred to a distinctively American machine and, in view of Mr. Tabor's mention of machines on the American market as being free from the trouble of mismatch, I am compelled to state that on the machines in which this very serious trouble exists, many users have resorted to putting the flask pins in the pattern plate itself to avoid this trouble. The vibrator frames in use on all Mumford machines from the very first have accomplished the same results to such an extent that the old construction has been and is being abandoned for the new on this type of machine with great enhancement of the value of the old machines constructed as described in my paper.

12 As to round flasks, there is no more use for a round flask in Europe than in America. Inadvertently I mentioned only the round flask in connection with the French production of what we know as snap molds without the use of snap flasks. This was an oversight, as

all shapes of flasks are used in the same way. The American founder is not different from any other founder in his liking, as Mr. Tabor says, "first, last and all the time" for saving sand in flasks, but sand is wasted in square corners on round work where square flasks only are available as it is wasted in round flasks on square work. The difference between putting square work in a round flask or round work in a square flask is a difference of only 6 per cent. Mr. Tabor's error in stating that the round flask "can have no place in this country," except for round castings will be made especially conspicuous by reference to The Foundry for April, in which a modern American steel foundry is shown largely equipped with round flasks built, "in twelve different sizes from 2½ ft. to 12½ ft. in diameter," and in which the reason for the use of the round flask is clearly stated as follows: "Many patterns conform to a flask of this shape, and the amount of sand required is much less than in the square flasks in which the corners carry large bodies of sand that are practically of no value, but nevertheless must be handled."

13 Many tons of these circular flasks are shown stacked in the foundry apparently almost to the exclusion of rectangular flasks.

14 The contention that the immemorial crude hand methods of "butt tucking," with a shovel, "finger tucking," "scooping out," etc., are or ever will be effective in ramming sand in deep pockets uniformly is untenable.

15 The reference to "complicated and expensive method" would seem to indicate that he has not studied or does not understand the very simple method of double-ramming employed in the universal system of machine molding by Messrs. Bonvillain and Ronceray. Mr. Tabor recommends, even in this discussion, the "stooling" of patterns. In the handling of stools, Mr. Tabor himself uses a plunger under his stool plate. The Frenchmen simply stop this plunger in its upward motion after it has compressed the sand over the stools enough and then withdraw the stop.

16 The regrettable lack of facilities for rapidly disposing of molds produced by complete molding machines and supplying sand to them has made the marker for incomplete light portable machines such as these. But the lack has developed a demand and no engineer ever failed to meet a demand based on a real need; so that now we are about to have these facilities for ordinary foundries; and the product of the highest mechanical intelligence embodied in machines can have fair play.

17 I do not disparage the able engineer who has had so fertile

a wit as to supply a handy hand molding machine which has been the best machine possible where a better machine would not have done more work—or done it better. But so far as the success of a machine is laid upon conditions, in themselves defective, it may be assumed that such a foundation will be replaced by the progressive foundry engineer and a superior product of engineering skill placed upon it.

18 I cannot close without noticing Mr. Tabor's statement that European patterns are less often changed than in America. I assume that he means that multiplicate castings from individual patterns on machines are in greater demand there than here.

19 Reference to my discussion of Mr. Berry's paper will show that I also have praised his work at Ilion, but, it must be admitted that I think this is a small department of the broad field of what he calls "molding machine engineering."

No. 1178

THE SPECIFIC HEAT OF SUPERHEATED STEAM

By PROF. CARL C. THOMAS, ITHACA, N. Y.
Non Member

The specific heat of superheated steam is of interest to engineers because upon it depend the answers to the two following questions:

a How much does it cost, with given efficiency of steam-heating apparatus, to produce superheated steam of given pressure and temperature, at a given rate?

b What amount of heat energy may be counted on as available in unit weight of superheated steam of given pressure and temperature?

2 Since the specific heat of any substance is the quantity of heat required to change the temperature of unit weight through one degree, and since this quantity may or may not depend upon the initial temperature and pressure of the substance under consideration, it follows that the specific heat may be practically constant, as in the case of water, or variable, as with gases. If the latter, the true specific heat *or specific heat at a point*, must be considered.

3 In some calculations it is necessary to have a knowledge of the value and law of variation of the *mean* specific heat, or the average amount of heat required per degree in changing the temperature of a substance from some assumed starting temperature to some other temperature. This *mean specific heat* is more often required in engineering calculations than is the *specific heat at a point*.

4 The results given in this paper show both true and mean specific heats of superheated steam, the mean being for temperature ranges starting at the saturation temperature.

5 The final form of apparatus was developed after a series of painstaking investigations extending over several years. These preliminary experiments are important in showing the advantage derived from certain improvements in the apparatus, and will therefore be first described.

Presented at the New York Meeting (December 1907) of The American Society of Mechanical Engineers, and forming part of Volume 29 of the Transactions.

6 Study of the characteristics of the flow of steam, superheated or otherwise, and with or without entrained water, have resulted in the development of the special apparatus devised by the author for the measurement of specific heat.

PRELIMINARY APPARATUS AND EXPERIMENTS

7 The following notes are intended to convey an understanding of the line of reasoning, and the method and apparatus employed by the writer and his assistants during the years 1905, 1906 and 1907.

8 The first experiments consisted in passing superheated steam through the bomb calorimeter shown in Fig. 1. In this calorimeter were electric resistance coils which served to raise the steam temperature from T_1 at entrance to T_2 at exit. The electrical energy and the subsequently condensed steam being measured, the mean specific heat could be calculated. A portion of the electrically supplied heat, however, was lost by radiation and conduction, notwithstanding the precautionary use of glass inlet and outlet tubes for the steam, and heat-insulating supports for the calorimeter.

9 Attempts to ascertain the radiation loss, by supplying just enough electrical energy to keep the temperature of the steam constant in its passage through the calorimeter, were but partially successful, owing to the impossibility of keeping surrounding conditions, or the rate of flow of the steam, unchanged during the various tests. The results of these experiments, about one hundred in number, are indicated in the lower right hand corner of Fig. 19.

10 A further disadvantage of this method and apparatus lay in the slightly higher pressure at the entrance thermometer than at the one at exit. This was obviated in the final experiments by employing only one thermometer, in a fixed position, for measuring both initial and final temperatures.

11 In order to eliminate various sources of error that had become apparent, two identical, electrically heated calorimeters were arranged in parallel, as shown in Fig. 2. Each containing shell was jacketed on the inside by steam at the initial temperature. The steam passed as indicated by the arrows, Fig. 1, through electric heating coils so insulated from the entering steam passage that the further superheating was supposed not to affect the temperature of the steam next the exterior walls of the calorimeter, thus insuring the same radiation from both instruments.

12 To one calorimeter was supplied electrical energy sufficient to raise the temperature from some convenient temperature, say 250

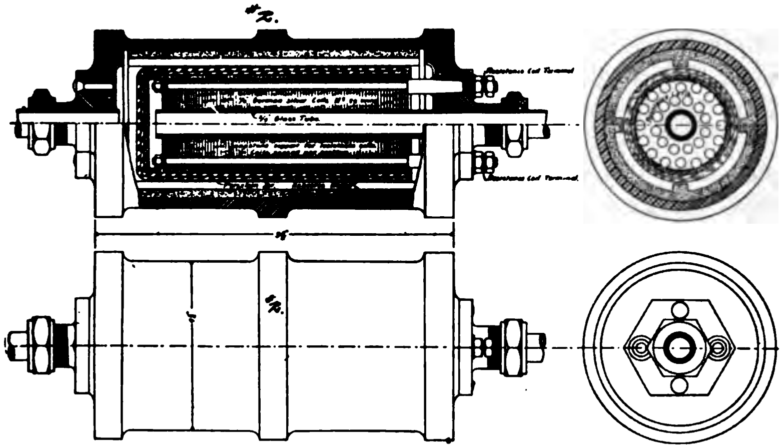


FIG. 1 SUPERHEATING CALORIMETER FOR DETERMINING THE SPECIFIC HEAT OF SUPERHEATED STEAM.

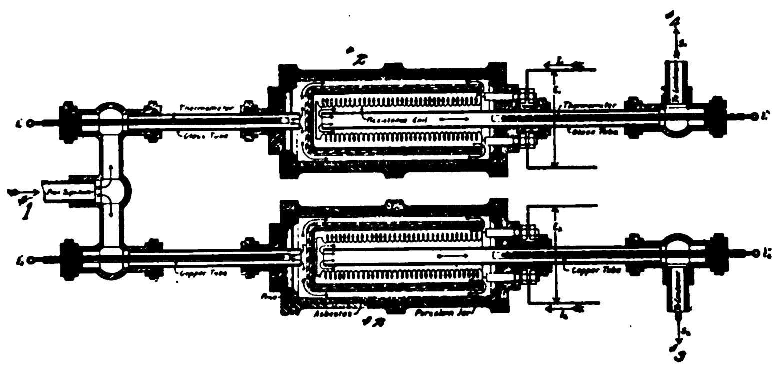


FIG. 2 SUPERHEATING CALORIMETER FOR DETERMINING THE SPECIFIC HEAT OF SUPERHEATED STEAM

degrees, to 270 degrees, and to the other to raise the temperature from the same initial temperature 250, to 290 degrees.

13 There being the same quantity of steam going through each calorimeter, and the radiation loss for each being the same, the difference in watts required to effect the different increases of temperature in the two calorimeters (in this case 20 degrees) represented the heat necessary to raise the given quantity of steam from 270 to 290 degrees.

14 Upon leaving the two calorimeters the steam passed through condensers, thence to accurately bored measuring tubes containing floats operating needle points. By so regulating the discharge valves of the calorimeters that the two needle points passed up the scale absolutely together, equal quantities of steam could be passed through the two calorimeters.

15 Glass tubes were employed at entrance and exit, in order to prevent conduction losses. The temperatures of incoming and outgoing steam were taken by means of thermo-couples placed in the glass inlet and outlet tubes.

16 In building up the apparatus, one after another of the causes of error in the previous investigation were attacked and eliminated by providing the following conditions:

a The production of a continuous supply of steam superheated to a given constant temperature and maintained at a given constant pressure. This was accomplished by passing steam from a small water tube boiler through an electric superheater, before which was placed a separator and a throttle valve. The steam pressure was kept uniform by a man at the throttle valve continuously observing a steam gage. The steam passing through the electric superheater at constant pressure was raised in temperature by a thoroughly controlled electrical input, until the steam, upon reaching the two calorimeters, was at the given desired initial condition, ready to be heated further in the calorimeters for determining the specific heat. The steam entered and left the two calorimeters through the glass tubes already described and passed directly over or around the thermo-couples for measuring temperature.

b A uniform supply of electrical energy at constant voltage, and a means of varying the amount of electrical energy between narrow limits. This was obtained by the use of a motor generator set equipped with a Tirrel regulator. The resistance used for controlling the amount of current consisted largely of incandescent lamps. These were used because they are not much affected by temperature changes in the room, currents of air, etc. The input of electrical energy was measured upon a single milli-voltmeter so arranged as to read both volts and amperes. This was done to avoid errors in reading two separate instruments.

c Means for absolutely measuring the temperature of the steam entering and leaving the calorimeters. After an extended experience with the best mercurial thermometers obtainable in this country and abroad, it was found that the lack of constancy of the mercurial thermometer rendered it totally unfit for this class of work. Temperatures were therefore measured by thermo-junctions which are readily inserted in the desired position and which can be calibrated with accuracy. Platinum resistance thermometers were tried but displaced in favor of the thermo-couples.

d Means for eliminating the errors introduced by radiation of heat from the apparatus. This was done as already described by arranging for equal radiation losses from the two instruments. To make sure that the radiation losses were the same from the two calorimeters, special radiation runs were made by passing superheated steam through the calorimeters and introducing just enough electrical energy to equalize the entering and exit temperatures.

e Means for thermally isolating the apparatus and thus minimizing the loss of heat by conduction through pipe connections and supports. The pipe connections were the glass tubes described, and the supports were wooden blocks covered with Portland cement upon which calorimeters rested.

f Means for obtaining a continuous measure of the amount of steam passing through the calorimeters; intermittent weighing of the condensed steam is not satisfactory. The continuous measure was obtained by using the uniform diameter tubes containing the floats actuating needle points.

17 The apparatus was operated by Mr. C. E. Burgoon, Fellow in Sibley College in 1905–1906, and the great care and skill he bestowed upon the work resulted in the performance of about one thousand experiments, the results of which are shown in the lower right hand

corner of Fig. 20. During this extensive set of experiments, however, it became apparent that the apparatus as a whole, while it provided for eliminating the errors described, was too complex and required too many accurate readings to be practical of operation to the degree of accuracy desired, under the circumstances. There were, for example, four thermo-junctions to be read as nearly simultaneously as possible; there was an auxiliary superheater to control;

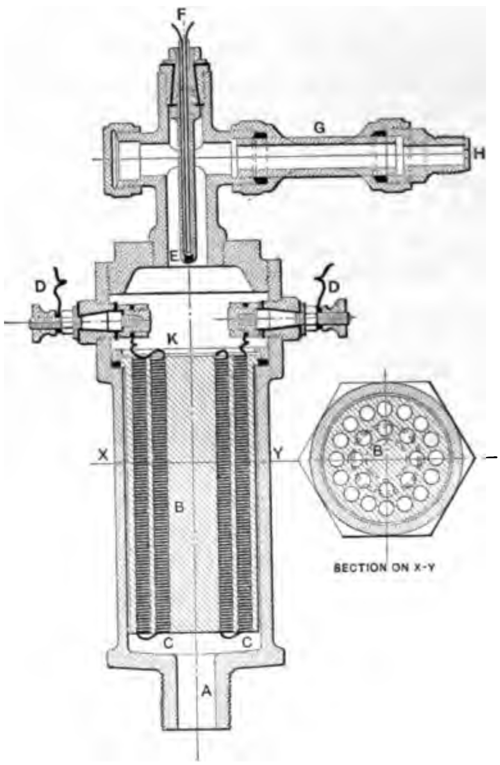


FIG. 3 CALORIMETER AS ARRANGED FOR DETERMINING THE SPECIFIC HEAT OF SUPERHEATED STEAM

A, Inlet to Calorimeter; B, Soapstone support for resistance coils; C, Resistance coils for heating steam; D–D, Electric terminals; E–F, Thermo junction and leads; G, Transparent glass outlet; H, Orifice.

there was the discharge from two calorimeters to regulate and to measure, and the electrical energy supplied to the two calorimeters as well as to the auxiliary superheater to be controlled. However these experiments, occupying about a year, gave fairly reliable values for the specific heat of superheated steam, and showed in a general way what has been proved by the later experiments to be the law of variation. But the more important service of the experiments was to show the necessity for greater simplicity of apparatus.

FINAL APPARATUS AND EXPERIMENTS

18 The regularity of the final results, presented on Fig. 5, 6, 7 and 8, is due primarily to the fact that the apparatus has been simplified by the discarding of a great deal of what formerly seemed essential. One of the chief improvements came with the development of the steam calorimeter shown in Fig. 3. This calorimeter, while it is used for determining the quality of steam, has, on account of its simplicity of construction and operation, been found specially well adapted for determining the specific heat of superheated steam.

19 The apparatus used in the final experiments consisted essentially of the following:

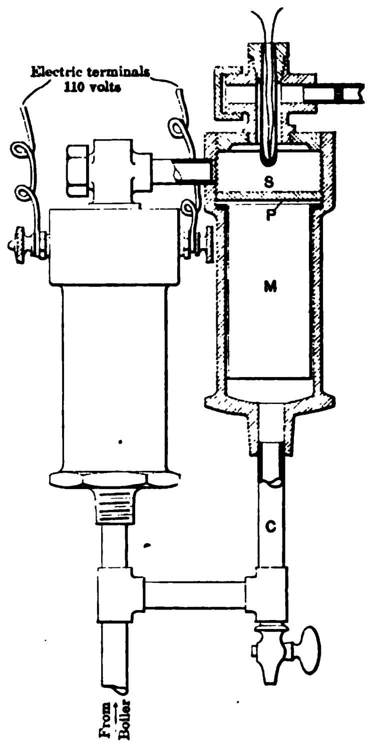
a A source of steam under complete control;

b A source of electrical energy under complete control;

c An electrically heated calorimeter containing a single thermo-junction, shown at *E F*, Fig. 3, introduced immediately into the steam and capable of accurately measuring the temperature of the same. The details of the apparatus are such that all conditions are under the control of an operator standing at a table where all readings are taken.

20 The calorimeter, Fig. 3, is in a vertical position and receives steam from the boiler and separator, through the steam entrance *A* to the calorimeter. This steam carries moisture along with it, into the small vertical holes containing the resistance coils *C*, Fig. 3.

21 If all the conditions are steady, and sufficient electrical energy is being introduced at a constant rate, the moisture is evaporated from the steam and the whole amount of steam is superheated to some fixed temperature depending upon the electrical energy supplied and the conditions of the entering steam. If the proportion of water brought in with the entering steam increases or decreases, the temperature as shown by the thermo-junction *E* indicates such change by an immediate fall or rise. Thus, if the percentage of water increases, the constant supply of electrical energy is not sufficient to raise the steam temperature as high as it could when it had less evaporation to perform before beginning to superheat. The relative constancy of all conditions is therefore shown by the degree to which the image on the screen showing the electromotive force of the thermo-junction *E*, remains fixed in position. It requires two or more hours'



G 4 THE ARRANGEMENT OF THE CALORIMETERS IN RUNS DURING WHICH THE NORMAL RADIATING SURFACE WAS DOUBLED

DESCRIPTION OF THE APPARATUS SHOWN IN FIG. 4

Apparatus as arranged during radiation runs, in which the radiating surface is double what it is in the regular runs. In the regular runs, steam passes through the left hand calorimeter only, the right hand calorimeter being removed entirely.

During runs for obtaining double radiation loss, heating is done in the left hand calorimeter only, and the steam is exposed to radiation from walls of space S, in the right hand calorimeter before its temperature is taken by means of the thermo-junction.

The plate P is screwed in and separates the lower part of the calorimeter from the upper part during runs for obtaining radiation loss values. The steam is not superheated, in regular runs, till it reaches the upper part, marked S, and the radiation loss occurs from space S, and not from that below. The lower space M is kept filled with wet steam during radiation runs.

The connection C is simply to keep the walls of the calorimeter hot, with steam of same temperature as was in contact with these walls during the experiments with normal radiation surface. This is to cause the conduction from the upper part, where the superheated steam is passing, to the the lower walls, which are jacketed with wet steam, to be the same as it was in the experiments with one calorimeter.

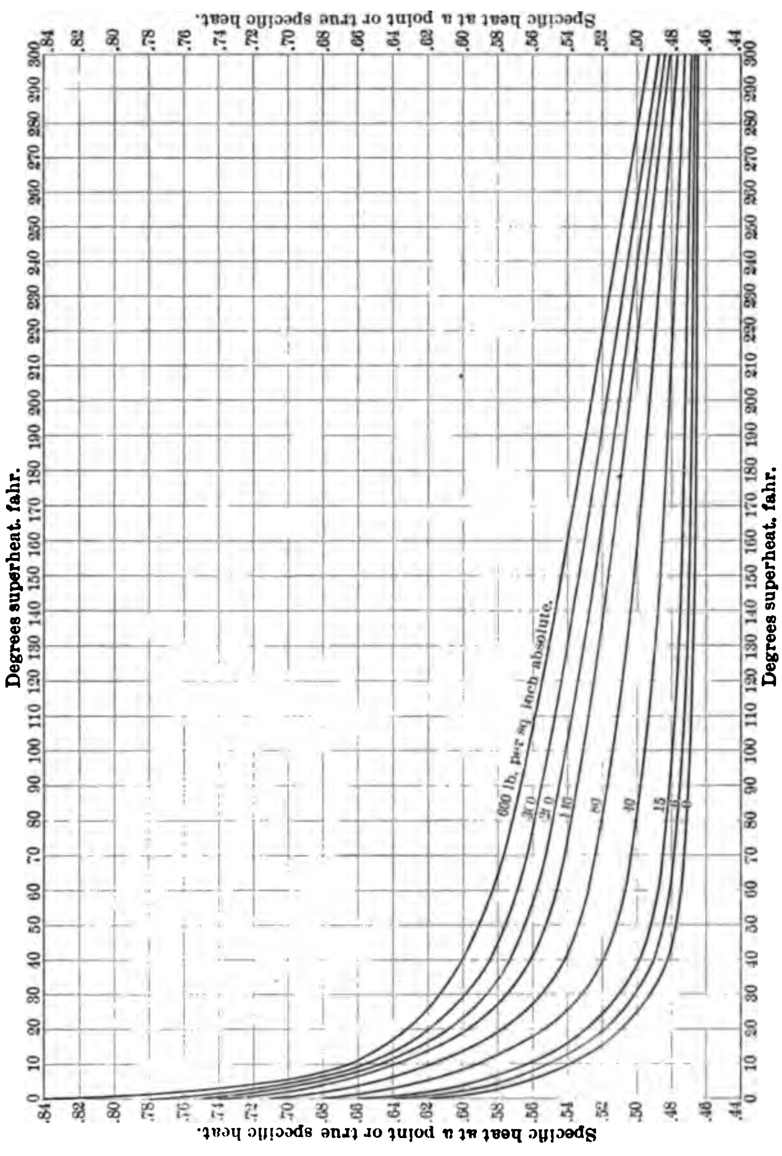


FIG. 5 VALUES OF TRUE SPECIFIC HEAT FOR DIFFERENT PRESSURES AND DEGREES SUPERHEAT

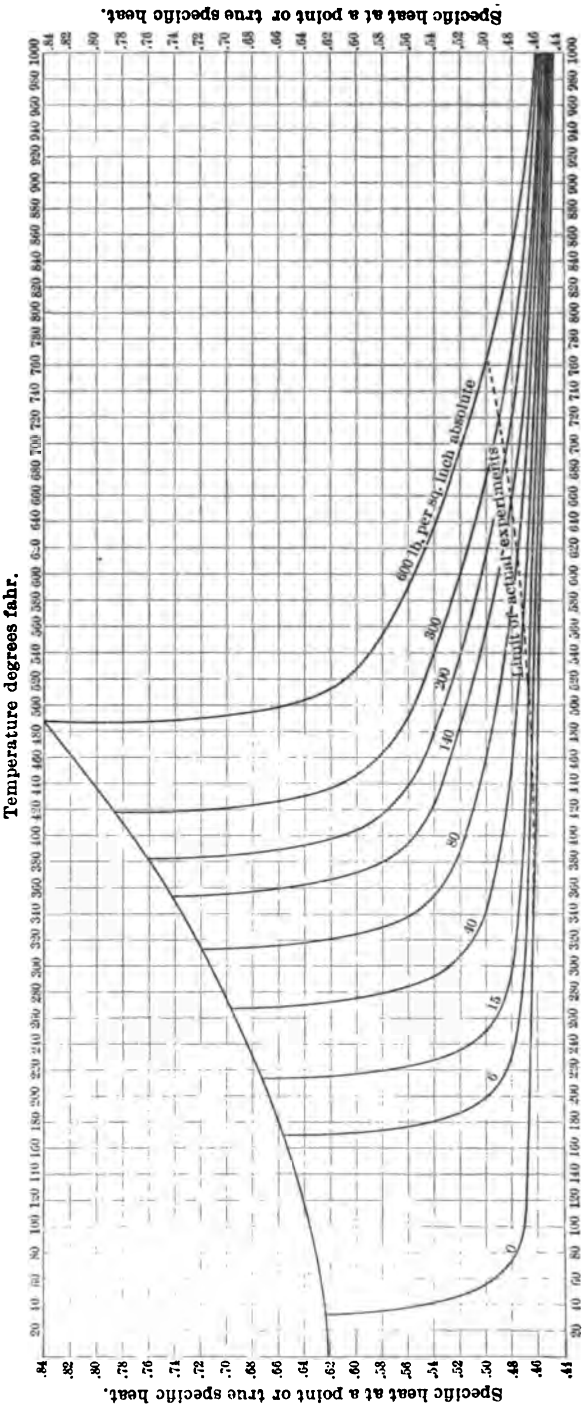


FIG. 6 RELATION OF TRUE SPECIFIC HEAT TO TEMPERATURE AND PRESSURE

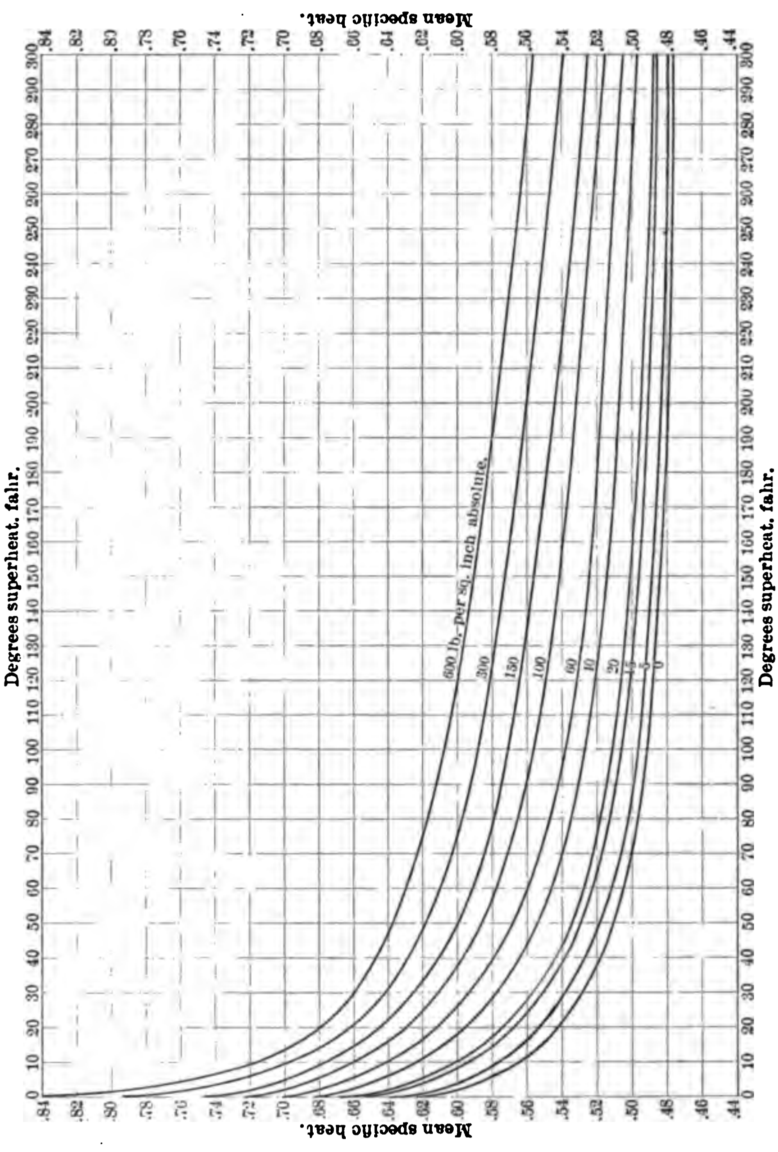


FIG. 7 VALUES OF MEAN SPECIFIC HEAT FOR DIFFERENT PRESSURES AND DEGREES SUPERHEAT

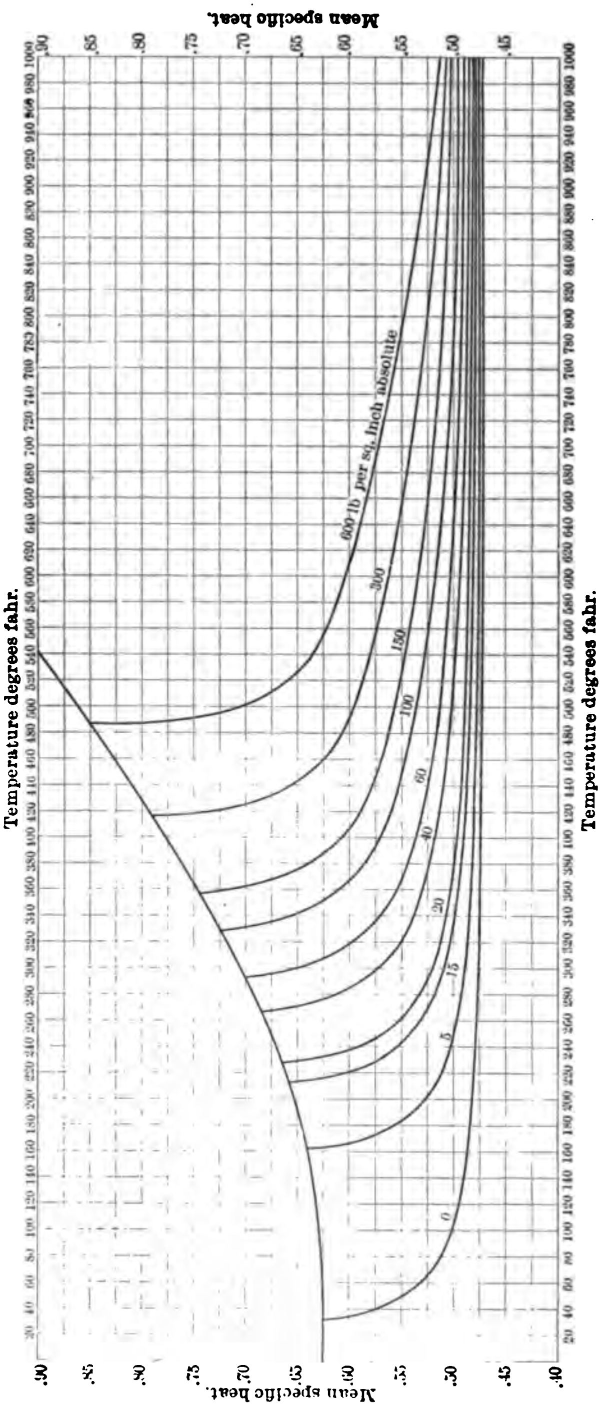


FIG. 8 RELATION OF MEAN SPECIFIC HEAT TO TEMPERATURE AND PRESSURE

time after starting the apparatus preparatory to making a test for all conditions to become absolutely steady. When the conditions have become steady, there is passing through the space above the heating coils *C*, and about the thermo-junction *E*, superheated steam of a given temperature and pressure, flowing at a given constant rate. The electrical energy supplied is doing the following three things:

a Evaporating the moisture brought in with the steam.

b Superheating the total amount of steam.

c Heating the surroundings because of radiation from the calorimeter.

22 The velocity of the steam through the coils is comparatively very low, from about one and one-half feet per second at 500 pounds pressure absolute, to 18 feet per second at 7 pounds pressure absolute. The higher velocity at low pressures is due to the greatly increased volume per pound of steam. The vertical position of the calorimeter is an important feature, first because the steam and water are distributed more nearly uniformly than they would be if the calorimeter were horizontal; second, because the superheated steam rises at once into the small space above the coils and attains a uniform temperature as it passes out through the constricted passage about the thermo-junction. The calorimeters in the series of experiments already described were horizontal.

23 The experience thus gained led to adopting the vertical position, and the advantages of this were at once apparent. By careful study of the steam as it passed through the glass exhaust nozzle, *G*, it was found that the thermo-junction would indicate no rise of temperature above that of saturated steam so long as water was going through with the steam. As soon as sufficient electrical energy was being introduced to make the water disappear however, any further addition of energy caused a rise of temperature of the steam. In a horizontal position the distribution of the contents of the calorimeter is not so uniform, and the indications of the thermometer are less reliable than when the calorimeter is vertical. In the vertical position, when water is passing with the steam it collects upon the tube of the thermo-junction as well as upon the walls of the passageway, and dripping down off the end of the junction causes the latter to be in contact with the water as long as there is any water present.

24 It is thus possible to know with certainty when the steam has just become dry and saturated, and to distinguish between this condition and that of either wet or of superheated steam. A feature which contributes to the uniform evaporation of water and superheating of steam is that the spiral heating coils present a sinuous

outline as one looks into the holes in the soapstone, and they prevent the vision from extending over the complete length of the holes. The steam and water are thus caused to come into very intimate and positive contact with the coils. The wire composing the coils is about 0.046 inches in diameter so that coils such as have been described present a considerable surface, and quite efficiently baffle the steam passing up through the 24 ¼-inch holes in the soapstone support.

25 After a sufficiently extended study had been made with the assistance of the glass outlet nozzle to render the determination of the saturation condition possible and positive, the glass was no longer used, and the apparatus was arranged and fitted up successively in the various ways shown in the sketches on Fig. 9, 10, 11 and 12.

METHODS BY WHICH THE RESULTS WERE OBTAINED AND CORROBORATED

26 The whole operation of drying the steam preparatory to evaporating it, and of superheating it to some desired temperature above that of saturation is done in the one calorimeter, shown in Fig. 3, and the temperatures are all read by means of one thermo-junction shown at *E F*. The apparatus thus consists essentially of one calorimeter, one thermometer, a source of steam and a source of heat in the form of electrical energy. It has been only through the discarding of one piece of apparatus after another, doing away with preliminary superheating, that the degree of uniformity shown by the curves has been made possible of attainment.

27 Briefly, the method used is as follows: All conditions having been arranged so that they can be controlled, thus providing for practically absolute steadiness of steam pressure, voltage and steam supply, steam is started through the calorimeter and the whole system is allowed to run for several hours before taking readings. When finally steady conditions have been obtained, steam of a certain quality is entering the calorimeter. Electrical energy is introduced sufficient to dry this steam as indicated by the thermo-junction in the calorimeter. Any change in quality is at once indicated by temperature change as previously described. Standard conditions having been obtained—that is, a given quantity of steam passing through the calorimeter per unit of time and receiving just enough electrical energy to dry it and thus bring it up to the "standard" or dry steam condition; then enough more electrical energy is added to raise the temperature of the steam through a given range, either 20, 40, 60, 80, 100 or 150 degrees cent. corresponding to 36, 72, 108, 144, 180 and 270 degrees fahr. respectively.

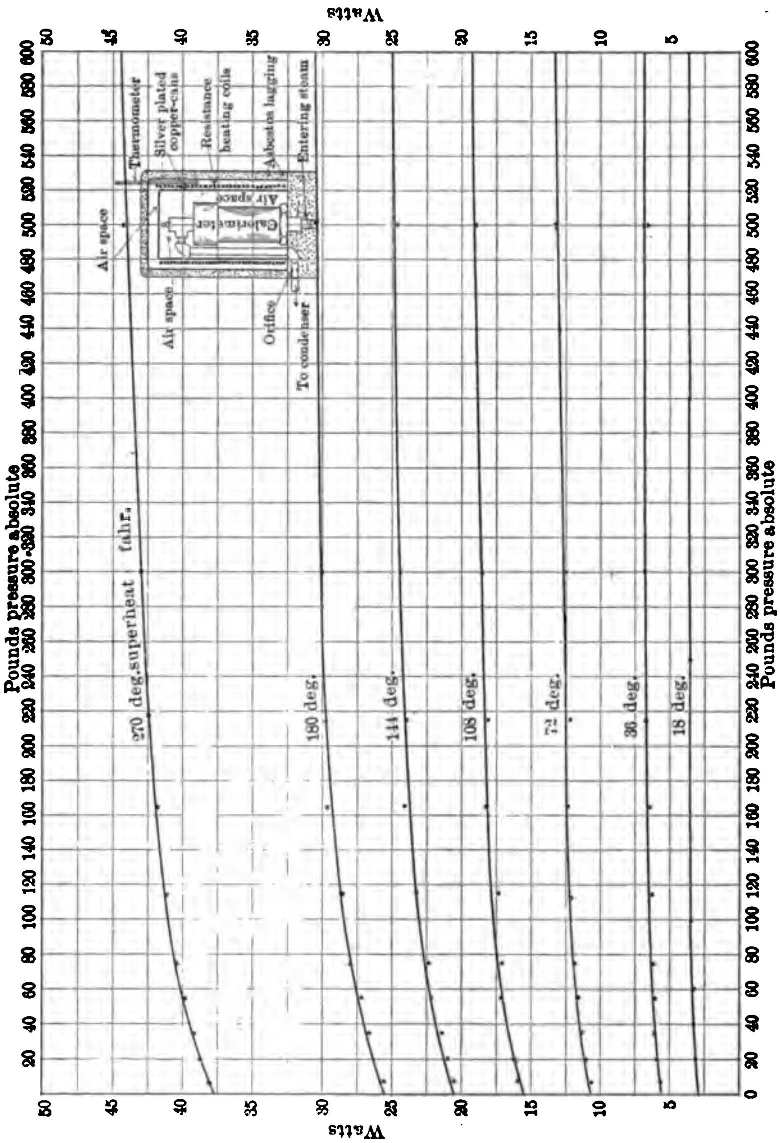


FIG. 9 CURVES SHOWING WATTS REQUIRED TO SUPERHEAT ONE POUND OF STEAM
RADIATION PREVENTED BY INDEPENDENTLY HEATED AIR JACKET AS SHOWN BY SKETCH

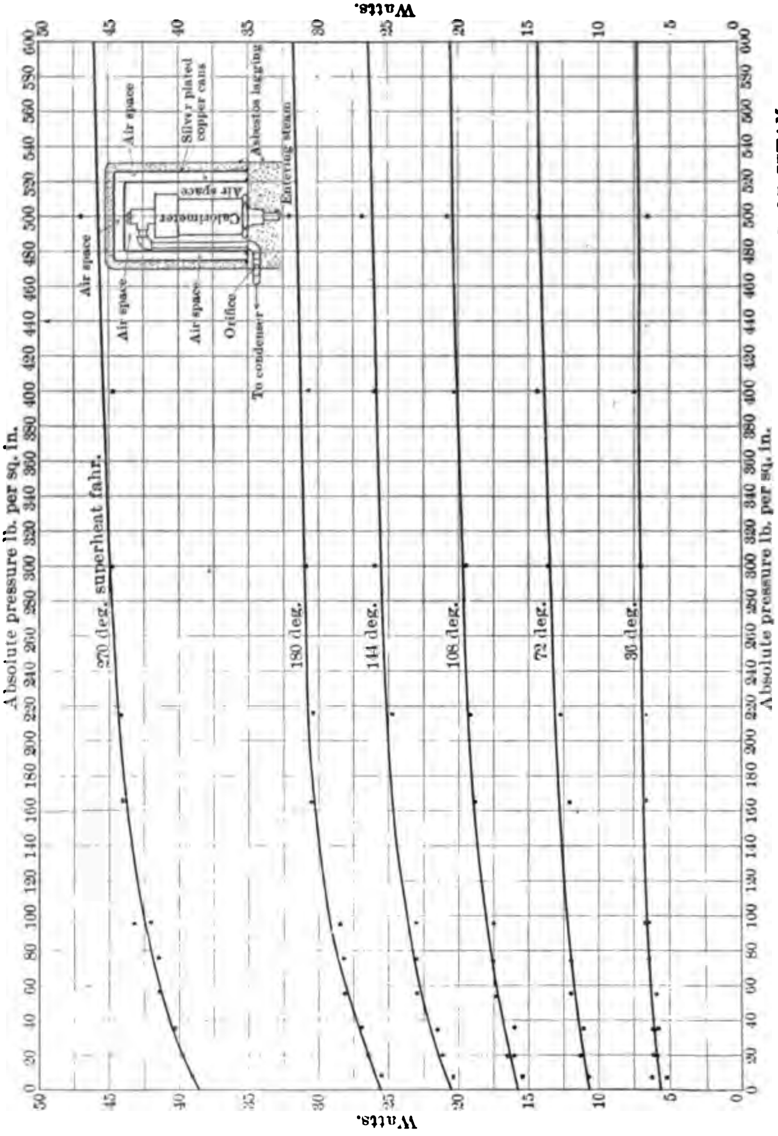


FIG. 10 CURVES SHOWING WATTS REQUIRED TO SUPERHEAT ONE POUND OF STEAM
RADIATION LOSSES REDUCED BY USING AIR JACKET AS SHOWN BY SKETCH

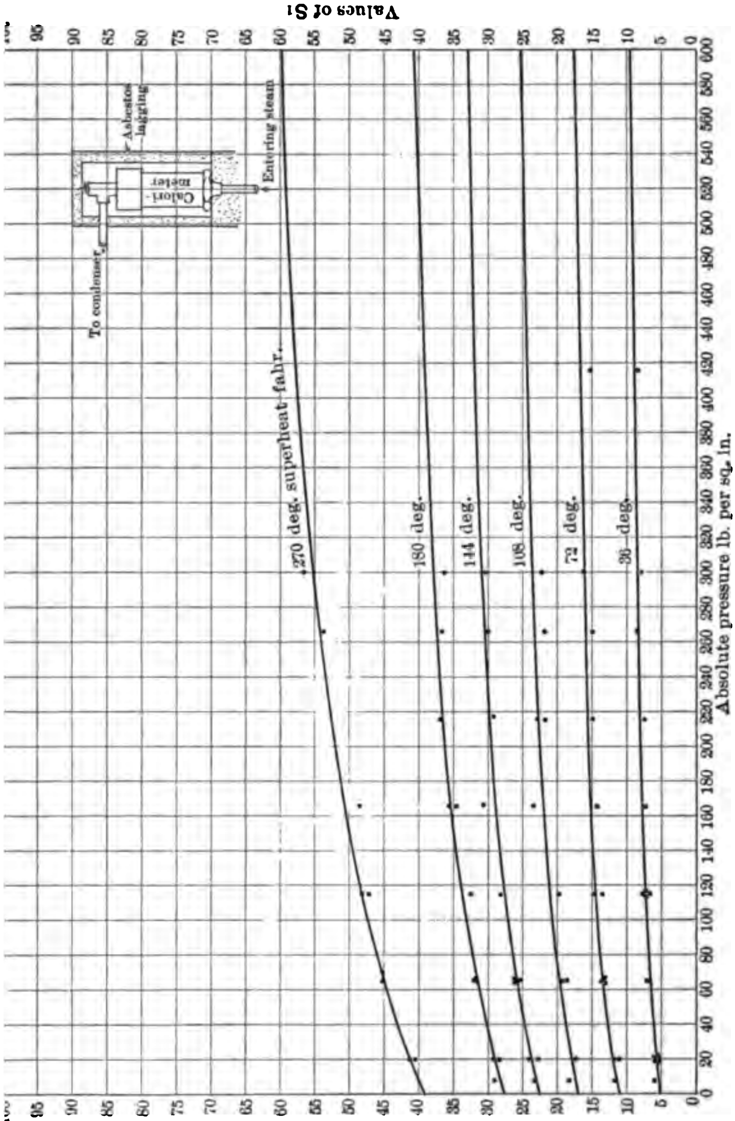


FIG. 11 CURVES SHOWING WATTS (S_1), REQUIRED TO SUPERHEAT ONE POUND OF STEAM INCLUDING NORMAL RADIATION LOSSES

POINTS SHOW ACTUAL VALUES, EXPERIMENTALLY OBTAINED

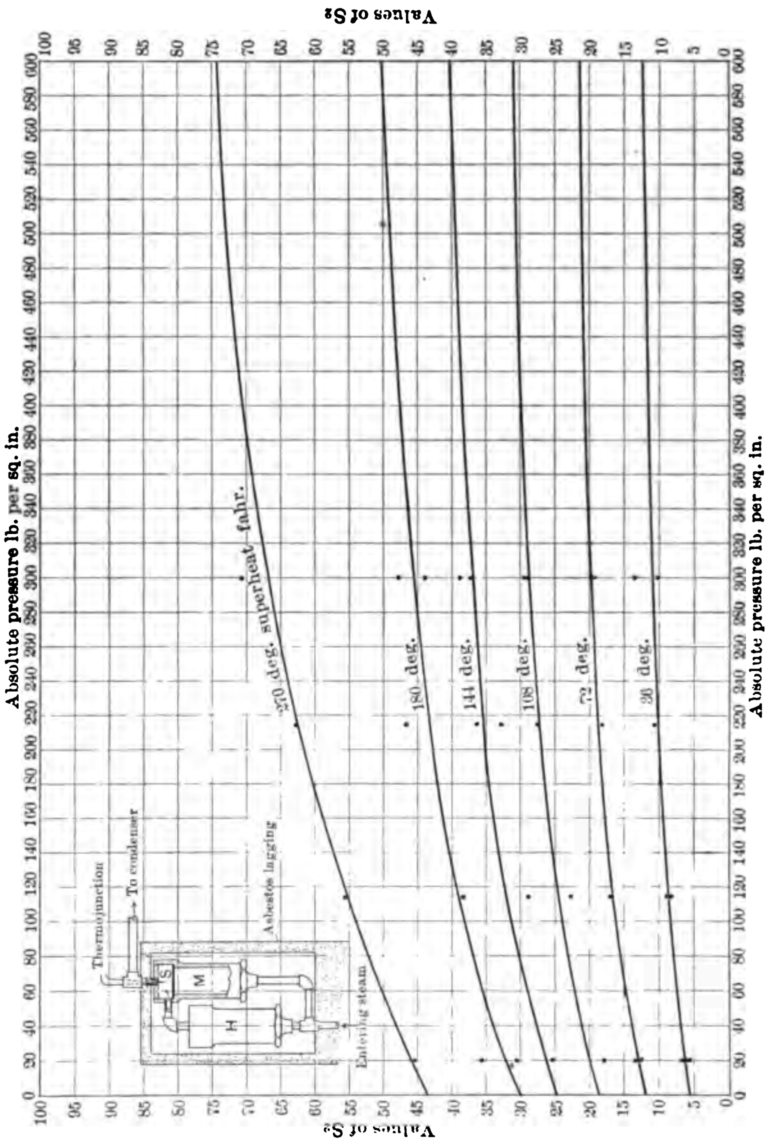


FIG. 12 CURVES SHOWING WATTS (S_2) REQUIRED TO SUPERHEAT ONE POUND OF STEAM INCLUDING TWICE THE NORMAL RADIATION LOSSES

Points Show Actual Values Experimentally Obtained

28 The energy required to produce this rise of temperature having been noted, the initial standard (dry and saturated) conditions are gone back to by dropping out the energy introduced to give the range of temperature. This forms a check on the constancy of the standard condition. From these data specific heats including radiation from the instrument are calculated for the various pressures and temperature ranges employed.

THE QUESTION OF CONDUCTION AND RADIATION LOSSES FROM THE CALORIMETER

29 To minimize conduction losses the calorimeter is connected to the piping leading to and from it by means of a thin steel tube, turned to approximately ½ inch outside diameter and bored $\frac{7}{16}$ inch inside.

30 To obtain a measure of the heat actually entering the steam entirely apart from radiation losses, and in order to verify the results, two independent methods were employed, and two independent sets of tests, each covering the entire field, were made as described below. Par. 31–39 describes the first method.

METHOD NO. 1

31 The first set of tests was made with the calorimeter simply lagged with magnesia sectional covering, as shown on Fig. 11. The whole range of pressures and temperatures was investigated with this arrangement. Then to find the radiation losses, the same experiments were repeated with the steam going through two calorimeters, exactly alike, and in series as shown in Fig. 4, and in sketch on Fig. 12, so that there was twice the radiating surface *exposed to superheated steam* in the second case that there was in the first. It of course required more energy to produce the same temperature with twice the radiating surface, than it required with the original single calorimeter. Fig. 4, shows the arrangement of the calorimeters during runs in which the normal radiating surface was doubled. The legend accompanying the figure explains the reasons for the arrangement employed.

32 The curves for single or "normal" radiation are shown on Fig. 11, and for double or "twice the normal" on Fig. 12. These runs were made from 7 pounds absolute to 300 pounds absolute, while the subsequent runs, by the second method, were made from 7 pounds absolute to 500 pounds absolute. The same degrees of superheat were used in the two cases.

33 The difference in energy required to produce the same temperature difference in the two sets of experiments, is equal to the radiation loss. The results, after deducting radiation losses, are

shown in Fig. 13, on which both constant temperature and constant pressure curves are drawn.

34 From the constant pressure curves the *true specific-heat* may be found as well as the *mean specific-heat*. On Fig. 14, are given the three sets of curves showing the watts required per pound steam for the various temperature ranges, including respectively twice the normal and the normal radiation losses, and also the watts required after deducting the radiation losses. The process will be made clearer by a reading of the following outline.

METHOD OF MAKING CALCULATIONS.

35 Let W_1 = weight of dry steam flowing per hour, in pounds;
W_2 = weight of superheated steam flowing per hour, in pounds;
E_1 = watts required to dry W_1 pounds steam per hour;
E_2 = watts required to dry and superheat W_2 pounds steam per hour through T degrees;
S = watts required to superheat 1 pound per hour through T degrees.

36 *Calculations including single radiation*, that is, radiation from one calorimeter. Let S_1 watts be required to superheat 1 pound steam per hour through T degrees including the watts radiated by the superheated steam

$$\text{Then } S_1 = \frac{E_2}{W_2} - \frac{E_1}{W_1}$$

37 *Double radiation* Let S_2 watts be required to superheat 1 pound per hour through T degrees when the steam is exposed to double radiation as shown in Fig. 4.

Then, if S equal the watts actually going into the steam per pound to raise its temperature T degrees,
When steam is exposed to single radiation

$$S_1 = S + \text{Radiation, or } 2S_1 = 2S + 2R$$

When steam is exposed to double radiation

$$S_2 = S + 2\text{Radiation, or } S_2 = S + 2R$$

$$\text{Subtracting,} \quad 2S_1 - S_2 = S$$

38 Since 1 watt hour = 3.412 B.t.u., the heat units required to raise one pound of steam through T degrees = 3.412 S, and the mean specific heat over that range of temperature is

$$C_p = \frac{3.412\ S}{T}$$

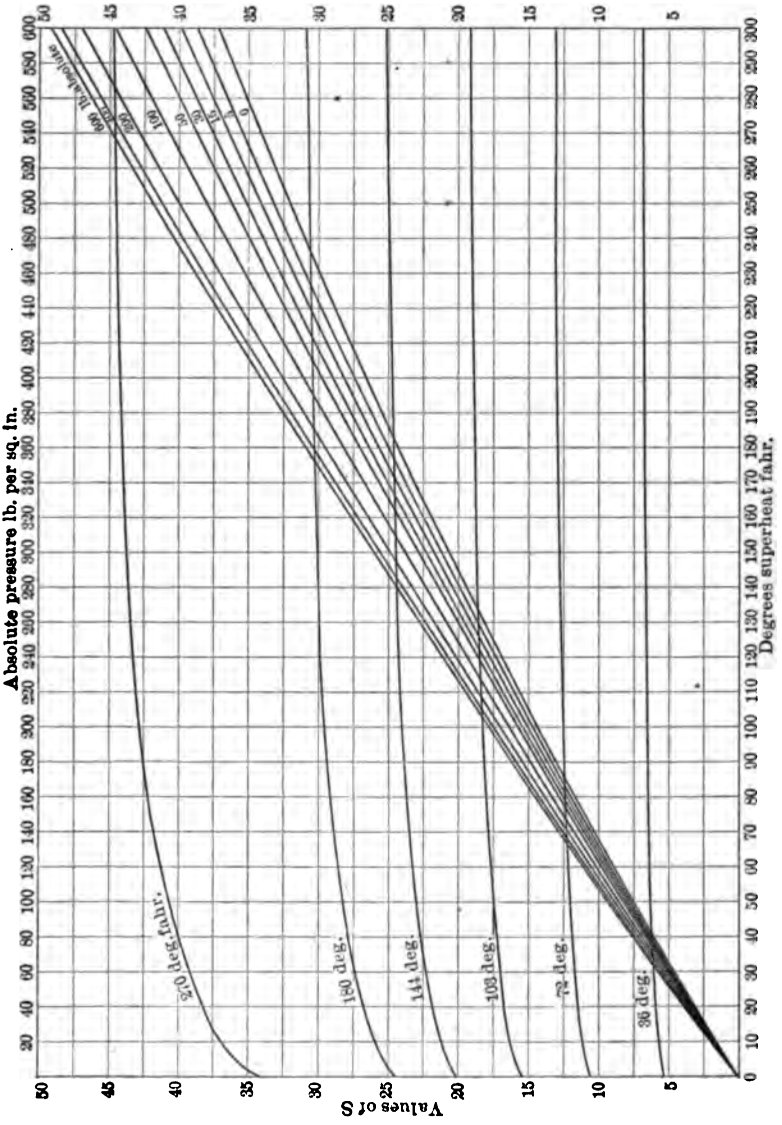


FIG. 13 CURVES SHOWING WATTS (S) REQUIRED TO SUPERHEAT ONE POUND OF STEAM WITH RADIATION LOSSES DEDUCTED

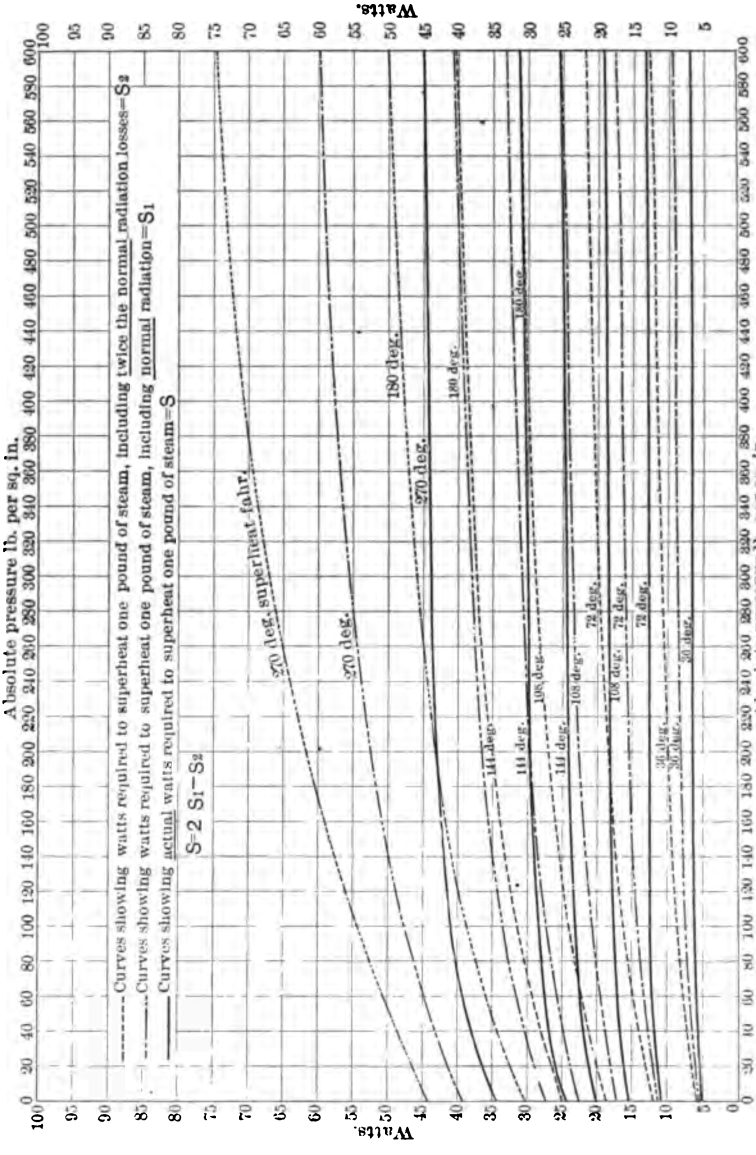


FIG. 14 CURVES SHOWING WATTS REQUIRED TO SUPERHEAT ONE POUND OF STEAM UNDER CONDITIONS NAMED

39 A study of the curves will show how important a feature the radiation from the calorimeter proved to be. Roughly, it varied from 12 per cent of the electrical energy introduced at low temperatures and pressures, to about 25 per cent at high temperatures and pressures.

SECOND METHOD

40 It now remains to be shown how the results just described were verified by an entirely different method of dealing with radiation, first by *greatly reducing radiation*, and making a complete series of tests. Second, by making the nearest possible approach to *eliminating radiation* and making another complete series of tests.

41 The reduction of radiation was accomplished by lagging consisting of two cylindrical silver-plated and polished copper cans, placed concentrically over the calorimeter as shown on Fig. 10. The cans rested upon a flat foundation of asbestos plastic, and the outer can was lagged with the same material. An air space thus existed between the calorimeter and the inner can, and one between the two cans themselves. The silvered and polished surfaces of the cans were for the purpose of reflecting the heat which tended to pass through the air spaces.

42 The result of the use of this lagging was the almost complete prevention of radiation. As an evidence of this the hand could be comfortably held on any part of the lagging even when the temperature in the calorimeter was 750 fahr. The curves obtained from this series of tests are shown on Fig. 10, and also by the broken lines on Fig. 15, where comparative results are shown. By inspection of the curves on Fig. 15 it will be noted that the radiation varied from about 1 to 4 per cent at low temperatures, to about 2½ to 5 per cent at high temperatures, the increase being with increase of pressure in all cases, as well as with increase of temperature.

43 Finally, a coil of resistance wire was introduced in the space between the two cans, as shown on Fig. 9, and a thermometer was used to ascertain the temperature resulting from passing current through this coil. A complete series of tests was again made during each of which the air jacket space between the two cans was maintained at a temperature equal to that to which the steam was being superheated in the calorimeter. The results are shown by the curves on Fig. 9 and in tabular form in Table 1.

44 The comparative results of the tests are shown on Fig. 15. The results obtained by correcting for radiation by doubling it, and those obtained by eliminating radiation with the independently heated air jacket coincide **almost absolutely for temperatures up to**

most easily obtained experimentally, because uniform conditions are so easily maintained when the independently heated air-jacket is employed.

45 The curves on Fig. 15 showing results obtained with the silvered can insulation but without introduction of heat in the air-space fall just as would be expected with reference to the results shown in full lines. That is, radiation was greatly reduced, almost completely in fact, by the reflecting cans alone, but there was still some heat lost, as is shown by the somewhat greater amount of energy required to produce a given result, than was required when radiation was eliminated. The difference in energy required is seen to be very small at low temperatures, and increases naturally as the temperature in the calorimeter increases.

46 The final results as given on Fig. 9 and in full lines on Fig. 15, have been transformed from watts to thermal units on Fig. 16 and 17. From Fig. 17 either the mean specific heat, or the specific heat at a point, may be taken off directly. The upper curves are simply the reproduction to larger scale of the lower curves for the first 30 degrees of superheat.

47 The apparatus has been left in just the condition last described, with the independently heated air jacket within the silvered copper cans, and various corroborative tests have been made besides those presented in this paper. It is possible at the present time to reproduce at will such results as are given on Fig. 9 with the apparatus as it now stands.

48 The zero line, or line of zero pressure, on Fig. 17, was obtained by extending the experimentally determined curves on Fig. 9 and 16 back to the line of zero pressure on those figures, by a process of fairing. Since the experiments included determinations at 7 pounds absolute pressure, the distance through which it was necessary to extend the curves was very small.

49 The curves on Fig. 9 were plotted from the original data, which are given in full in Table 1.

50 In this connection it is of interest to note that the lowest number of degrees of superheat used in the experiments made before August 1, 1907 was 20 degrees cent. or 36 degrees fahr. It was later desired to corroborate the results obtained by extending the curves on Fig. 17 from the 20 degrees cent. points through zero, which had been done by the process of fairing the curves, aided by certain experimentally determined points obtained during low superheat runs. Two months and a half after the experimental work originally contemplated was finished, it was decided to explore the region of 10

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degrees cent. superheat (18 degrees fahr.) and the curve shown at the bottom of Fig. 9 shows the results of these experiments. By computing specific heat from this curve as reproduced in thermal units on Fig. 16 it will be found that the curves on Fig. 17 are completely checked and verified, for a position midway between zero degrees superheat, and 20 degrees cent. that is, at 10 degrees cent. or 18 degrees fahr.

(*g*) COMPARISON OF RESULTS WITH THOSE OBTAINED IN VARIOUS OTHER INVESTIGATIONS OF THE SUBJECT

51 That the specific heat of steam is not constant has been believed by physicists and engineers for some years, and testimony from many sources has been unanimous in confirming the belief that it varies in some way; either with change of temperature, or of pressure, or with both temperature and pressure.

52 In 1904 the writer had occasion to make use of values of the total heat of superheated steam, and as a matter of convenience plotted constant-pressure and constant-heat curves in a temperature-entropy diagram, using values for the specific-heat of superheated steam such as had been published at various times. The first set of values used, assumed the specific heat to vary with the pressure only, the variations being represented about as shown in the lower right hand corner of Fig. 19. The resulting constant-heat curves are shown by the broken lines BB. The values of constant-heat are seen to plot into fairly smooth curves until the curve of 1250 thermal units is reached, although that curve begins to show uncertainty of character. As higher values for the heat contents are used, such as 1300, 1350, etc., the curves become more and more irregular, finally entirely departing from the characteristics possessed by the curves of lower heat contents. In other words, the curves do not form a uniform set, or family, showing similar characteristics. Examination in this manner, of various results at that time available, formed the initial step, showing the necessity for, and leading on to, the present investigation.

53 It should be said here, that the mere fact that certain values, assumed to represent the specific heat of steam, plot into smooth curves, is not necessarily any indication that those values do really represent the specific heat of steam, or of any other substance. But if any assumed values of specific heat, or of any other physical characteristic in nature, do *not* plot into curves of a common family, it is highly probable that the correct determining coefficients have not

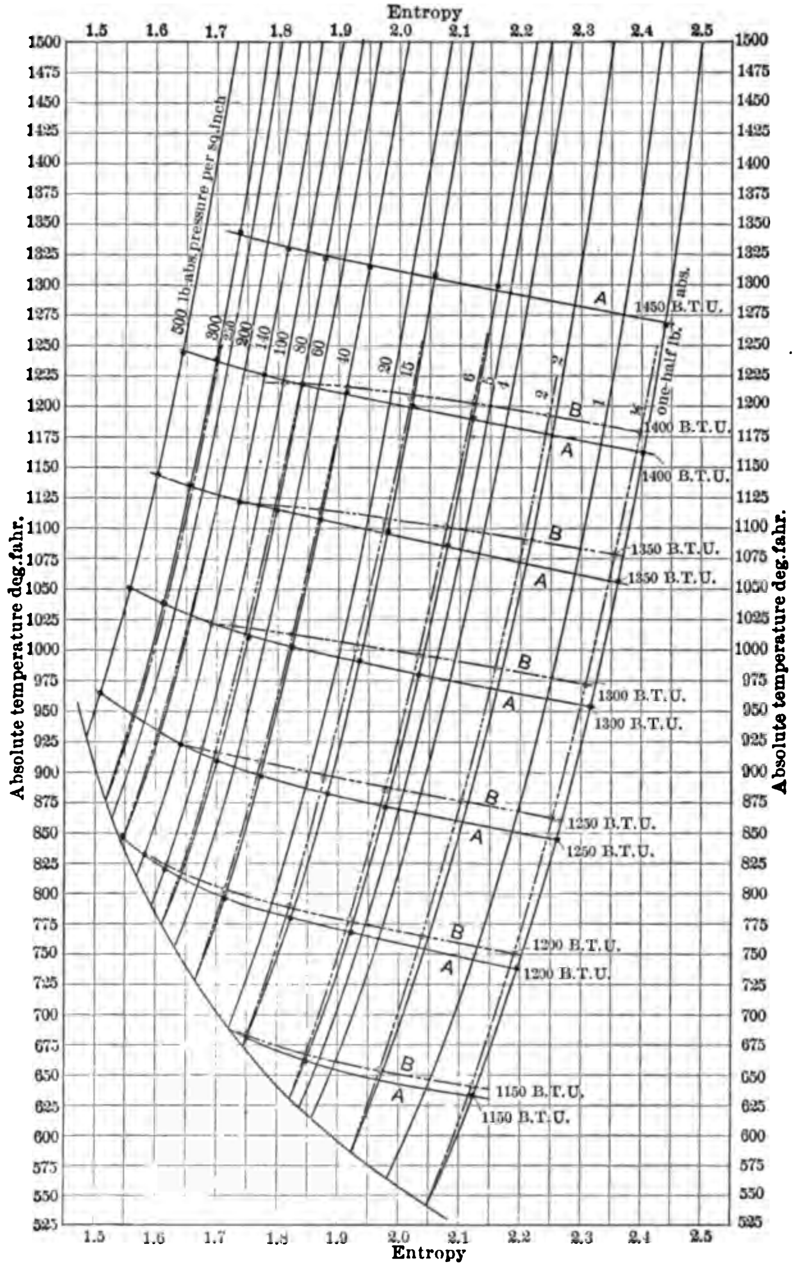
been used. Many curves however, could be found and used tentatively to represent the variation of the specific heat, which would, for mathematical reasons, modify the expressions used in calculation of the heat-diagram so as to give smooth and related curves.

54 For example, the use of a *constant* value will give a family of regular constant-pressure and constant-heat curves. The curves AA, Fig. 19, are plotted with the value 0.48, and are seen to fall into a family of smooth curves, as would be expected from mathematical considerations, to be the case for any constant value. But, for the reasons stated, this does not prove that the actual specific heat has a constant value. Curves CC on the same plate show the results obtained in the present investigation and are seen to fall into one family maintaining definite and regular characteristics.

55 On Fig. 20 the results obtained by Mr. Burgoon with the apparatus shown in Fig. 1 and 2 are plotted in the lower right hand corner, and constant-pressure and constant-heat lines are plotted for the superheated region of a temperature entropy diagram. At about 1270 thermal units the curves of constant heat begin to be uncertain in character, and above that value they gradually change direction, finally assuming entirely different characteristics from the lower heat curves.

56 On Fig. 18, the black points are those belonging to the results of the present investigation. The curves marked A, through them retain the same characteristics throughout, even up to the highest temperatures and pressures. The points for 6 and for 15 pounds absolute, at very high temperatures, are slightly higher than the curve but not enough to change its character.

57 The broken line curves, marked B, Fig. 18, are plotted from the results of the work of Messrs. Knoblauch and Jakob, published in the *Zeitschrift des Vereins Deutscher Ingenieure*, Vol. 51, page 81, 1907. At 1250 thermal-units, the curve of constant-heat begins to waver, but is almost straight, and at higher values the curves turn down at the high pressure ends, tending to depart more and more from the family characteristic. This is largely due to the fact that the curves of specific heat as determined by these investigators show a decrease of the specific heat with increasing temperature until a minimum is reached, for each pressure, after which the specific heat *increases* with increase of temperature. An increase in the value given to the specific heat tends to lower the curves of constant-heat, because the greater the specific heat, the smaller will be the temperature range through which it is necessary to heat the steam in order to give it a certain increase in heat-contents.



'IG. 18 CONSTANT PRESSURE AND CONSTANT HEAT CURVES: A, FROM THE AUTHOR'S RESULTS; B, FROM RESULTS BY KNOBLAUCH AND JAKOB

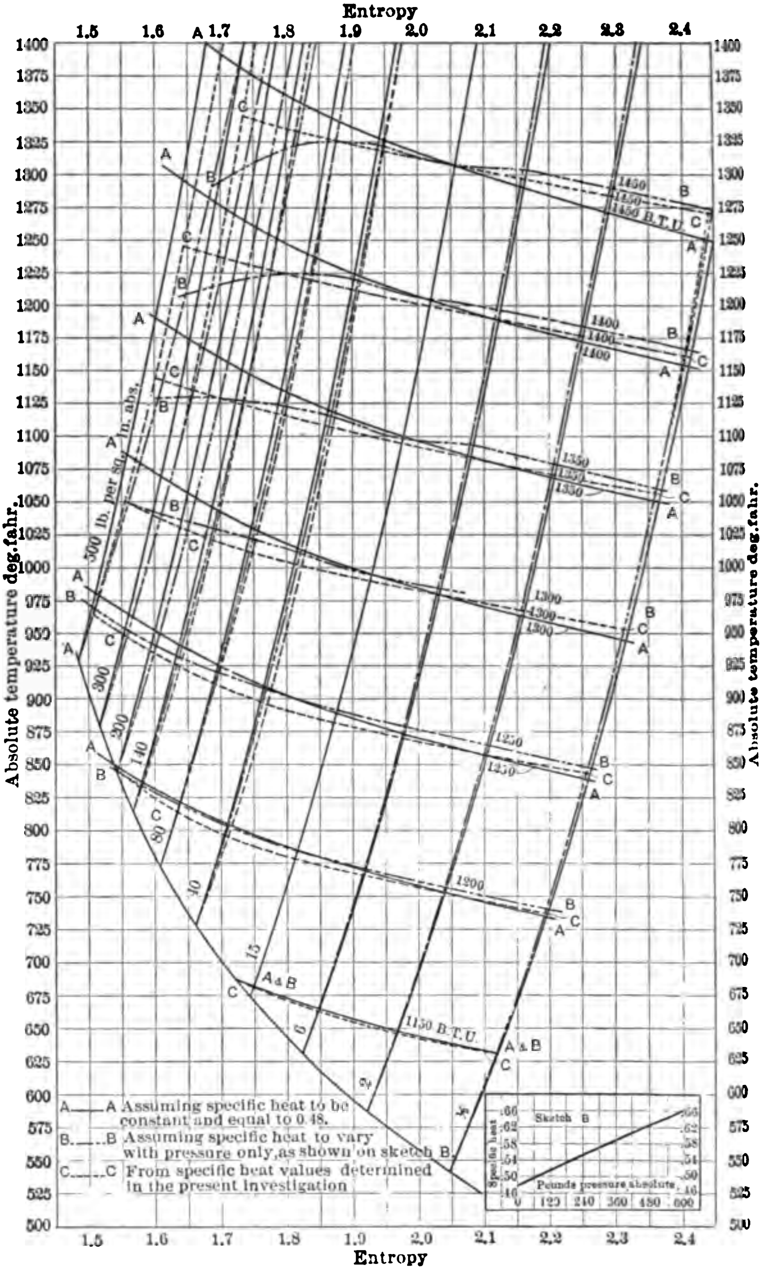


FIG. 19 CONSTANT HEAT AND CONSTANT PRESSURE CURVES FOR CONDITIONS ASSUMED UNDER A, B AND C

58 On the other hand, a continually decreasing specific heat tends to keep the high pressure ends of the constant-heat curves up and to cause the curves to remain in one family. It will be appreciated readily that the higher the temperature and pressure to which one is attempting to work experimentally, the more difficult it is to control radiation losses. If these losses are not thoroughly allowed for an experimenter is likely to arrive at too high values for specific heat in the higher temperature ranges, because, due to unaccounted for radiation losses, it *appears* that more heat is being expended to superheat the steam than is in reality going into the steam. The author had this experience in early investigations and it is probable that it has been the common experience and one which led to the belief some years ago that the specific heat of steam was very much higher than it has since been proved to be.

59 It will be noted from Fig. 18 that the constant heat curves, plotted from the values of specific heat given by Messrs. Knoblauch and Jacob are in general quite closely in agreement with the results of the present investigation excepting where the change in method of variation occurs, but the lack of regularity of the constant-heat curves plotted from their results indicates that the true law of variation of specific heat is not expressed by the curves, for the entire range of temperature covered by the experiments.

CONCLUSIONS

a The specific-heat of superheated steam varies with both pressure and temperature. It increases when the pressure of the steam increases and diminishes with an increase in the temperature.

b The specific heat increases and decreases more rapidly when near the saturation point, with increase of pressure and temperature, respectively, than is the case in conditions more remote from the saturation point.

c These conclusions apply over the whole range covered in the present investigation, which include pressures from seven pounds absolute to five hundred pounds absolute per square inch and up to 270 degrees fahr. superheat, for all pressures employed. The values of the specific heat and the laws of variation are shown on Fig. 5, 6, 7 and 8 inclusive.

d The Mollier Heat Diagram, Fig. 21, forms a graphical steam table, the superheated region of which has been calculated from the results of the present investigation.

METHOD OF RECORDING DATA FROM TESTS AND OF MAKING CALCULATIONS, IN FINAL EXPERIMENTS

TEST ON SPECFIC HEAT OF SUPERHEATED STEAM

Test no. ....

Date..19............

Pressure........................lb. absolute

Temperature of steam leaving calorimeter ....cent..........................fahr.

Temperature of steam entering calorimeter ....cent..........................fahr.

Rise of Temperature in Calorimeter ....cent..........................fahr.

Time of ending test ....hr.................min.................sec.

Time of starting test ....hr.................min.................sec.

Duration of test ....hr.................min.................sec.

Water gage at end of test................lb.

Water gage at beginning of test................lb.

Water obtained during test..............lb. when E_1 watts are being introduced.

Water obtained during test..............lb. when E_2 watts are being introduced.

E_1 = Watts req'd to dry ....lb. steam per hr. = ...

E_2 = Watts req'd to dry and superheat................lb. steam per hr. = ...

Pounds superheated steam flowing per hr..................... = W_2

Pounds dry steam flowing per hr..................... = W_1

True amp..................... True Volts.................... Watts...................

Room temp.....................cent.....................fahr.

Condensed steam temp.....................cent.....................fahr.

Microvolts................Corresponding temp.................cent.................fahr.

$\frac{E_2}{W_2}$ = Watts req'd. to dry and superheat one lb. steam. = ...

$\frac{E_1}{W_1}$ = Watts req'd. to dry one lb. steam = ...

$S = \frac{E_2}{W_2} - \frac{E_1}{W_1}$ = Watts req'd. to superheat one lb. steam = ...

60 The writer wishes to express his appreciation of the assistance that he has received from a large number of colleagues and workers in allied lines, for without the coöperation of others it would have been impossible to carry to completion the investigation forming the subject of this paper. Particularly, the interest of Mr. E. W. Rice, vice president and chief engineer of the General Electric Company, and the constant interest and assistance given to the work by Dr. W. R. Whitney, director of the research laboratory, General Electric Company, and that of Dr. W. D. Coolidge of the same laboratory have been very largely the sustaining influences throughout the investigation. The apparatus used in the experiments, aside from that furnished by Sibley College, Cornell University, was all loaned by order of the above named officials of the General Electric Company, and the author had frequent occasion to consult with members of the staff of the research laboratory regarding the details of the work.

FOLDER 2

METHOD OF RECORDING DATA FROM TESTS AND OF MAKING CALCULATIONS, IN FINAL EXPERIMENTS

TEST ON SPECFIC HEAT OF SUPERHEATED STEAM

Test no. ....

Date......................................19...........

Pressure.......................lb. absolute

Temperature of steam leaving calorimeter ....cent..........................fahr.

Temperature of steam entering calorimeter ....cent..........................fahr.

Rise of Temperature in Calorimeter ....cent..........................fahr.

Time of ending test ....hr................min.................sec.

Time of starting test ....hr................min.................sec.

Duration of test ....hr................min.................sec.

Water gage at end of test................lb.

Water gage at beginning of test................lb.

Water obtained during test..............lb. when E_1 watts are being introduced.

Water obtained during test..............lb. when E_2 watts are being introduced.

E_1 = Watts req'd to dry ....lb. steam per hr. = ...

E_2 = Watts req'd to dry and superheat................lb. steam per hr. = ...

Pounds superheated steam flowing per hr.................... = W_2

Pounds dry steam flowing per hr.................... = W_1

True amp..................... True Volts................... Watts...................

Room temp.....................cent.....................fahr.

Condensed steam temp.....................cent.....................fahr.

Microvolts................Corresponding temp.................cent.................fahr.

$\frac{E_2}{W_2}$ = Watts req'd. to dry and superheat one lb. steam. = ...

$\frac{E_1}{W_1}$ = Watts req'd. to dry one lb. steam = ...

$S = \frac{E_2}{W_2} - \frac{E_1}{W_1}$ = Watts req'd. to superheat one lb. steam = ...

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FOLDER 2

METHOD OF RECORDING DATA FROM TESTS AND OF MAKING CALCULATIONS, IN FINAL EXPERIMENTS

TEST ON SPECIFIC HEAT OF SUPERHEATED STEAM

Test no. ....

Date.......................................19...........

Pressure.......................lb. absolute

Temperature of steam leaving calorimeter ....cent.........................fahr.

Temperature of steam entering calorimeter ....cent.........................fahr.

Rise of Temperature in Calorimeter ....cent.........................fahr.

Time of ending test ....hr................min.................sec.

Time of starting test ....hr................min.................sec.

Duration of test ....hr................min.................sec.

Water gage at end of test................lb.

Water gage at beginning of test................lb.

Water obtained during test.............lb. when E_1 watts are being introduced.

Water obtained during test.............lb. when E_2 watts are being introduced.

E_1 = Watts req'd to dry ....lb. steam per hr. = ...

E_2 = Watts req'd to dry and superheat................lb. steam per hr. = ...

Pounds superheated steam flowing per hr.................... = W_2

Pounds dry steam flowing per hr.................... = W_1

True amp.................... True Volts................... Watts...................

Room temp.....................cent.....................fahr.

Condensed steam temp....................cent.....................fahr.

Microvolts................Corresponding temp.................cent.................fahr.

$\frac{E_2}{W_2}$ = Watts req'd. to dry and superheat one lb. steam. = ...

$\frac{E_1}{W_1}$ = Watts req'd. to dry one lb. steam = ...

$S = \frac{E_2}{W_2} - \frac{E_1}{W_1}$ = Watts req'd. to superheat one lb. steam = ...

60 The writer wishes to express his appreciation of the assistance that he has received from a large number of colleagues and workers in allied lines, for without the coöperation of others it would have been impossible to carry to completion the investigation forming the subject of this paper. Particularly, the interest of Mr. E. W. Rice, vice president and chief engineer of the General Electric Company, and the constant interest and assistance given to the work by Dr. W. R. Whitney, director of the research laboratory, General Electric Company, and that of Dr. W. D. Coolidge of the same laboratory have been very largely the sustaining influences throughout the investigation. The apparatus used in the experiments, aside from that furnished by Sibley College, Cornell University, was all loaned by order of the above named officials of the General Electric Company, and the author had frequent occasion to consult with members of the staff of the research laboratory regarding the details of the work.

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FOLDER 3

61 Through the influence of Prof. R. C. Carpenter, the water-tube boiler used in the tests was kindly supplied by the White Automobile Company of Cleveland, and to Professor Carpenter and to Dr. J. S. Shearer of the department of physics, Cornell University, especial thanks are due for their continued interest and assistance in supplying apparatus for the work.

62 The investigation has been made possible by the support and encouragement given by Sibley College, which has supplied everything needed for the work aside from what has already been mentioned as coming from outside sources.

63 The writer has been especially fortunate in having the active assistance of Mr. C. E. Burgoon and Mr. F. J. Short, both men of mechanical and scientific abilities, who were elected to fellowships in Sibley College during the years 1905–1906 and 1906–1907 respectively, and who came prepared by experience obtained in active engineering positions for the purpose of doing advanced research work in mechanical and electrical engineering. Mr. Burgoon's work has already been referred to in the body of the article as of great assistance in developing the apparatus and methods employed. Mr. Short came into the work when the reconstruction of the entire apparatus was in hand and by most persistent and intelligent attention to details was very helpful in bringing the apparatus to its present state of completeness and ease of operation. Mr. Short operated the apparatus during the past year 1906–1907 with great skill and care and to his work is largely due the regularity of the results obtained. He has been of great assistance also in the preparation of the curves as presented in this paper.

64 In closing the writer wishes to refer again to the methods used before he began his investigations, because he feels that he owes a debt of gratitude to the men who tried them out, unsatisfactory though they proved to be. They enabled him to begin at a point much farther along than would have been otherwise possible. Particularly of value in this respect was the work carried on through a period of several years in Sibley College under the direction of Professor Carpenter, using first the method of expanding into a throttling calorimeter, then of heating by gas, and lastly, of heating electrically, according to the method first tried by the writer. While all of these methods were discarded by the writer as unreliable, they formed a stepping stone from which he was able to work toward satisfactory results. Those results, therefore, he presents as the fruit not only of his own final method but of all who worked before him.

TABLE 1

ORIGINAL DATA, PLOTTED ON PLATES 1 TO 7 INCLUSIVE

TEST NUMBER	DATE 1907	PRESS. LBS. PER SQ. IN. ABS.	TEMP. OF STEAM LEAVING CAL. CENT.	TEMP. OF STEAM ENTERING CAL. CENT.	RISE OF TEMP. IN CALORIMETER, CENT.	DURATION OF TEST. MINUTES AND SECONDS	LBS. WATER OBTAINED DURING TEST, WHEN E_1 WATTS ARE BEING INTRODUCED	LBS. WATER OBTAINED DURING TEST, WHEN E_2 WATTS ARE BEING INTRODUCED	E_1 WATTS. REQ'D TO DRY W_1 LBS. STEAM PER HR.	E_2 WATTS REQ'D TO DRY AND SUPERHEAT W_2 LBS. STEAM PER HOUR.	POUNDS SUPERHEATED STEAM FLOWING PER HR. = W_2	POUNDS DRY STEAM FLOWING PER HOUR. = W_1	WATTS	ROOM TEMP. CENT.	CONDENSED STEAM TEMPERATURE, CENT	MICROVOLTS	CORRESPONDING TEMPERATURE CENT.	$\frac{E_2}{W_2}$ = WATTS REQ'D TO DRY AND SUPERHEAT ONE LB. STEAM	$\frac{E_1}{W_1}$ = WATTS REQ'D TO DRY ONE LB. STEAM	$s=\frac{E_2}{W_2}-\frac{E_1}{W_1}$ — WATTS REQ'D TO SUPERHEAT ONE LB. STEAM
1	8-6	7	80.	80.	0	14-35	3		65.			12.3	65	27	28	4 210	80.		3.4	
2	8-6	7	100.	80.	20	16-15		3		100	11.1		100	27	28	5 300	100.	9.	3.4	5.6
3	8-6	7	120.	80.	40	11-10		2		150	10.7		150	27	28	6 400	120.	14.	2.4	10.6
4	8-6	7	140.	80.	60	11-40		2		198	10.3		198	27	28	7 470	140.	19.2	3.4	15.8
5	8-6	7	160.	80.	80	11-10		2		255	10.7		255	27	28	8 560	160.	23.8	3.4	20.4
6	8-6	7	180.	80.	100	21-0		4		330	11.4		330	27	28	9 660	180.	28.9	3.4	25.5
7	8-6	7	230.	80.	150	21-40		4		465	11.2		465	27	28	12 440	230.	41.6	3.4	38.2
8	7-24	20	109.	109.	0	6-10	3		90.			29.2	90	27	28	5 800	109.		3.1	
9	7-24	20	129.	109.	20	6-40		3		240	27.		240	27	28	6 870	129.	8.9	3.1	5.8
10	7-24	20	149.	109.	40	11-27		5		370	26.2		370	27	28	7 960	149.	14.1	3.1	11.0
11	7-24	20	169.	109.	60	11-30		5		505	26.1		505	27	28	9 060	169.	19.3	3.1	16.2
12	7-24	20	189.	109.	80	11-60		5		610	25.4		610	27	28	10 170	189.	24.	3.1	20.9
13	7-24	20	209.	109.	100	6-18		3		720	24.7		720	27	28	11 270	209.	29.1	3.1	26.
14	7-24	20	259.	109.	150	7-27		3		1010	24.1		1010	27	28	14 060	259.	41.9	3.1	38.8
15	7-24	35	126.	126.	0	5-27	3		155.			33.	155	27	28	6 710	126.		4.7	
16	7-24	35	146.	126.	20	5-40		3		340	31.8		340	27	28	7 800	146.	10.7	4.7	6.
17	7-24	35	166.	126.	40	9-22		5		510	32.		510	27	28	8 900	166.	16.	4.7	11.3
18	7-24	35	186.	126.	60	9-55		5		645	30.3		645	27	28	10 000	186.	21.3	4.7	16.6
19	7-24	35	206.	126.	80	9-55		5		780	30.		780	27	28	11 110	206.	26.	4.7	21.3
20	7-25	35	226.	126.	100	8-30		3		680	21.2		680	27	28	12 210	226.	32.	5.3	26.7
21	7-25	35	126.	126.	0	8-0	3		110			22.5	110	27	28	6 710	126.		5.3	
22	7-25	35	276.	126.	150	14-35		5		920	20.6		920	27	28	15 040	276.	44.6	5.3	39.3
23	7-25	55	141.5	141.5	0	5 6	3		180.			35.3	180	27	28	7 550	141.5		5.4	

TABLE 1 (Continued)

24	7-25	55	161.5	141.5	20	8-40		5		400	34.7		400	27	28	8 650	161.5	11.5	5.4	6.1
25	7-25	55	181.5	141.5	40	8-55		5		570	33.7		570	27	28	9 750	181.5	17.	5.4	11.6
26	7-25	55	201.5	141.5	60	9-0		5		750	33.3		750	27	28	10 850	201.5	22.5	5.4	17.1
27	7-25	55	221.5	141.5	80	5-50		3		850	31.		850	27	28	11 980	221.5	27.5	5.4	22.1
28	7-25	55	241.5	141.5	100	9-30		5		1030	31.6		1030	27	28	13 100	241.5	32.6	5.4	27.2
29	7-25	55	291.5	141.5	150	10-7		5		1350	29.7		1350	27	28	15 910	291.5	45.4	5.4	40.
30	7-26	75	153.	153.	0	12-15	3		225.			14.7	225	27	28	8 180	153.		15.3	
31	7-26	75	173.	153.	20	12-30		3		310	14.4		310	27	28	9 300	173.	21.5	15.3	6.2
32	7-26	75	193.	153.	40	12-50		3		380	14.		380	27	28	10 400	193.	27.1	15.3	11.8
33	7-26	75	213.	153.	60	13-15		3		440	13.6		440	27	28	11 500	213.	32.3	15.3	17.
34	7-26	75	233.	153.	80	13-27		3		500	13.3		500	27	28	12 600	233.	37.7	15.3	22.4
35	7-26	75	253.	153.	100	13-35		3		570	13.2		570	27	28	13 740	253.	43.2	15.3	27.9
36	7-26	75	303.	153.	150	14-0		3		715	12.8		715	27	28	16 570	303.	55.8	15.3	40.5
37	7-26	115	170.	170.	0	8-6	3		230.			22.3	230	27	28	9 110	170.		10.3	
38	7-26	115	170.	170.	0	8-6	3		255.			22.3	255	27	28	9 110	170.		11.4	
39	7-26	115.	190.	170.	20	8-6		3		370		22.3	370	27	28	10 210	190.	16.6	10.3	6.3
40	7-26	115	210.	170.	40	8-36		3	490.			20.9	490	27	28	11 330	210.	23.5	11.4	12.1
41	7-26	115	230.	170.	60	9-5		3		570	19.8		570	27	28	12 440	230.	28.8	11.4	17.4
42	7-26	115	250.	170.	80	9-0		3		680	19.7		680	27	28	13 560	250.	34.6	11.4	23.2
43	7-26	115	210.	170.	100	9-0		3		790	19.7		790	27	28	14 700	270.	40.	11.4	28.6
44	7-26	115	320.	170.	150	9-35		3		990	18.8		990	27	28	17 540	320.	52.7	11.4	41.3
45	7-31	165	185.	185.	0	15-30	3		370.			11.6	370	27	28	9 950	185.		31.9	
46	7-31	165	185.	185.	0	14-30	3		385.			12.4	385	27	28	9 950	185.		31.	
47	7-31	165	205.	185.	20	15-0		3		450	12.		450	27	28	11 050	205.	37.5	31.	6.5
48	7-31	165	225.	185.	40	15-30		3		503	11.6		503	27	28	12 160	225.	43.4	31.	12.4
49	7-31	165	245.	185.	60	15-34		3		570	11.35		570	27	28	13 270	245.	50.2	32.	18.2
50	7-31	165	265.	185.	80	16-30		3		610	10.9		610	27	28	14 410	265.	56.	31.9	24.1
51	7-31	165	285.	185.	100	16-40		3		665	10.8		665	27	28	15 550	285.	61.5	31.9	29.6
52	7-31	165	335.	185.	150	17-30		3		760	10.3		760	27	28	18 400	335.	73.8	31.9	41.9
53	8-1	215	197.5	197.5	0	11-10	3		190.			16.2	190	27	28	10 640	197.5		11.8	
54	8-1	215	217.5	197.5	20	11-50		3		280	15.2		280	27	28	11 750	217.5	18.4	11.8	6.6
55	8-1	215	237.5	197.5	40	12-0		3		360	15.		360	27	28	12 860	237.5	24.	11.8	12.2
56	8-1	215	257.5	197.5	60	12-25		3		435	14.5		435	27	28	14 000	257.5	30.	11.8	18.2
57	8-1	215	277.5	197.5	80	12-45		3		505	14.1		505	27	28	15 130	277.5	35.8	11.8	24.
58	8-1	215	297.5	197.5	100	13-15		3		565	13.6		565	27	28	16 250	297.5	41.6	11.8	29.8
59	8-1	215	347.5	197.5	150	14-10		3		690	12.7		690	27	28	19 130	347.5	54.3	11.8	42.5
60	8-1	300	214.	214.	0	8-50	3		310.			20.4	310	27	28	11 550	214.		15.2	

TABLE 1 (Continued)

61	8–1	300	234.	214.	20	9–10		3		430	19.7		430	27	28	12 660	234.	21.9	15.2	6.7
62	8–1	300	254.	214.	40	9–5		3		550	19.8		550	27	28	13 790	254.	27.8	15.2	12.6
63	8–1	300	274.	214.	60	9–20		3		650	19.3		650	27	28	14 930	274.	33.7	15.2	18.5
64	8–1	300	294.	214.	80	9–30		3		750	19.		750	27	28	16 050	294.	39.5	15.2	24.3
65	8–1	300	314.	214.	100	9–50		3		830	18.3		830	27	28	17 200	314.	45.3	15.2	30.1
66	8–3	300	214.	214.	0	10–30	3		370.			17.2	370	27	28	11 550	214.		21.5	
67	8–3	300	364.	214.	150	20–20		5		950	14.8		950	27	28	20 090	364.	64.5	21.5	43.
68	8–5	500	242.	242.	0	6–55			415			26.1	415	27	28	13 100	242.		16.	
69	8–3	500	242.	242.	0	10–30	5		355.			26.	355	27	28	13 100	242.		13.6	
70	8–3	500	242.	242.	0	6–55			420.			26.	420	27	28	13 100	242.		16.3	
71	8–5	500	242.	242.	0	10–55			360.			27.5	360	27	28	13 100	242.		13.	
72	8–5	500	262.	242.	20	6–45				530	26.7		530	27	28	14 240	262.	9.8	13.	6.8
73	8–3	500	262.	242.	20	7–0				520	25.7		520	27	28	14 250	262.	20.2	13.6	6.6
74	8–3	500	282.	242.	40	7–0				690	25.7		690	27	28	15 370	282.	26.8	13.6	13.2
75	8–5	500	282.	242.	40	6–45				700	26.7		700	27	28	15 370	282.	26.2	13.	13.2
76	8–3	500	302.	242.	60	7–12				880	25.		880	27	28	16 520	302.	35.2	16.3	18.9
77	8–5	500	322.	242.	80	7–6				1030	25.4		1030	27	28	17 650	322.	40.6	16.	24.6
78	8–5	500	342.	242.	100	7–30				1120	24.		1120	27	28	18 810	342.	46.7	16.	30.7
79	8–5	500	392.	242.	150	7–45				1400	23.3		1400	27	28	21 730	392.	60.2	16.	44.2
80	10–14	20	109.	109.	0	12–30	3		120.			14.4	120	28	21	5 800	109.		8.33	
81	10–14	20	119.	109.	10	12–30		3		165	14.4		165	28	21	6 330	119.	11.43	8.33	3.1
82	10–15	40	130.5	130.5	0	10–53	5		157.			27.6	157	28	21	6 950	130.5		5.68	
83	10–15	40	140.5	130.5	10	11–5		5		240	27.		240	28	21	7 500	140.5	8.9	5.68	3.22
84	10–15	40	130.5	130.5	0	10–53	5		160.			27.6	160	28	21	6 950	130.5		5.8	
85	10–15	40	140.5	130.5	10	10–55		5		245	27.5		245	28	21	7 500	140.5	8.98	5.8	3.18
86	10–15	60	145.	145.	0	7–47	5		205.			38.5	205	28	21	7 755	145.		5.33	
87	10–15	60	155.	145.	10	7–47		5		328	38.5		328	28	21	8 300	155.	8.53	5.33	3.2
88	10–15	100	164.	164.	0	4–50	5		280.			62.	280	28	21	8 780	164.		4.51	
89	10–15	100	174.	164.	10	4–50		5		490	62.		490	28	21	9 340	174.	7.9	4.51	3.39
90	10–15	250	205.	205.	0	5–4	5		310.			59.3	310	28	21	11 050	205.		5.23	
91	10–15	250	215.	205.	10	5–7		5		515	58.7		515	28	21	11 600	215.	8.77	5.23	3.54
92	10–15	400	229.	220.	0	6–54	5		160.			43.5	160	28	21	12 380	229.		3.68	
93	10–15	400	239.	229.	10	7–0		5		310	42.8		310	28	21	12 940	239.	7.24	3.68	3.56

DISCUSSION

PROF. C. H. PEABODY[1] It gives me great pleasure to express my high appreciation of the importance of the experimental work presented by Professor Thomas to this Society and to the engineering profession in his paper on "The Specific Heat of Superheated Steam."

2 The importance of settling the vexed question of the specific heat of superheated steam is so well understood, and the sufficiency of the methods used by Professor Thomas are so evident from his presentation that it is not necessary to enlarge on the subject. Rather I will proceed at once to show what use I have myself made of his results, more especially as I believe this will put in evidence the advantages that the profession can derive from his labors and the reliance that can be placed on his work.

3 Early in the summer Professor Thomas sent me photographic prints of curves showing results of experiments on the specific heat of superheated steam made under his direction and incorporated in the graduation thesis of Mr. Short. These curves gave the mean specific heats in each instance at a certain pressure, between the temperature at saturation and a series of higher temperatures. For my purposes I desired also to know the specific heat *at* those several points, which properly could be determined from Mr. Short's curves by differentiation. The curves thus obtained were faired by cross-curves which had the effect of distributing accidental error both of experiment and of the graphical operations. A great advantage of this operation was that it gave means of making a direct comparison with the very important investigations by Knoblauch and Jakob recorded in the *Mitteilungen uber Forschungsarbeiten, etc., Heft 36, p. 109*. Fig. 1 shows the result of this method of comparison at the pressure of 100 pounds absolute. The apparent discrepancy is due, in part, to the relatively large scale of the ordinates; it will be shown presently that the apparent discrepancy may properly be considered as in reality a good check on the results by two radically different methods.

4 A criticism, favorable or otherwise, of their work would be out of place here, but it may be proper to say that they appeared to have some difficulty in maintaining constant pressures over the very large periods of time required for their experiments, and that the distribution of points on their diagrams appears to show that an allowable

[1]Professor of Engineering, Massachusetts Institute of Technology.

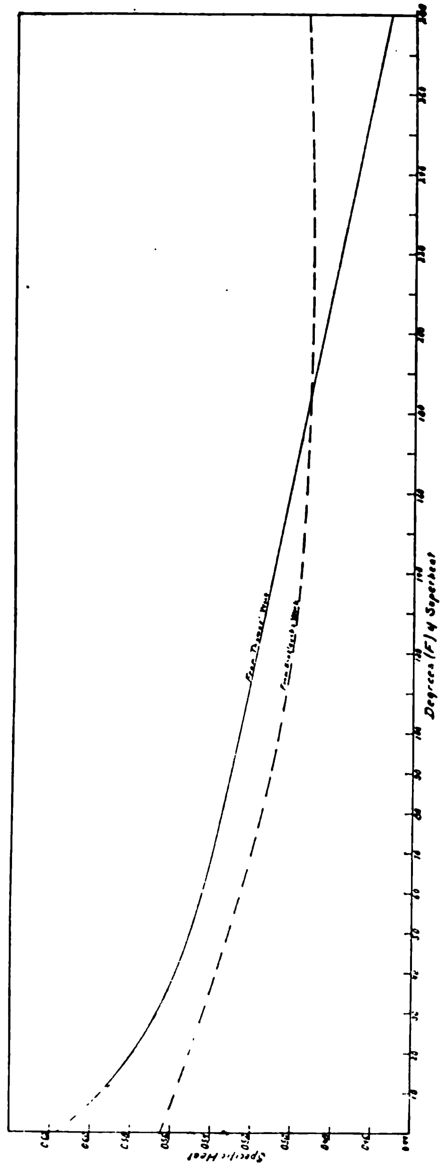

FIG. 1 COMPARISON OF RESULTS OF THOMAS AND KNOBLAUCH AND JAKOB

latitude in drawing their curves would have made them approach nearer to those I have derived from Professor Thomas's work. It is much to be regretted that their apparatus did not allow them to go above eight atmospheres or about 113 pounds absolute.

5 There are two important properties that may be computed from the specific heat of superheated steam, namely, the heat required to superheat the steam, and the increase of entropy due to superheating. The first may be represented by

$$\int c_p \, dt,$$

and the second by the expression

$$\int \frac{c_p \, dt}{T}.$$

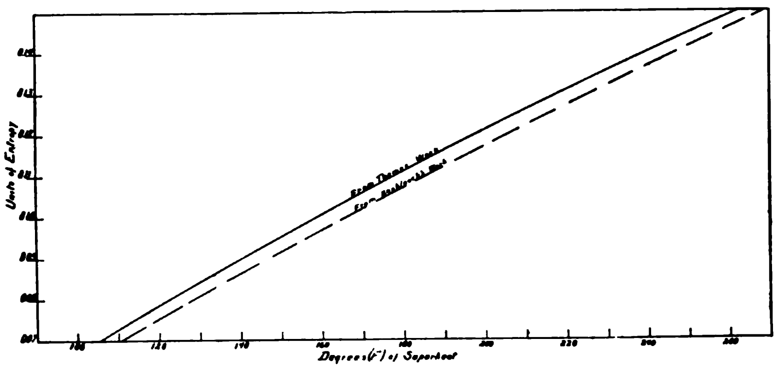

FIG. 2 DIAGRAM SHOWING DISCREPANCY BETWEEN RESULTS INDICATED IN FIG. 1

Here c_p is the variable specific heat, represented by curves like Fig. 1, and T is the absolute temperature. Both of these results were obtained for my purposes by aid of a large integraph which was carefully tested and found to be both delicate and accurate.

6 To get the heat required to superheat the steam it was sufficient to run the instrument over curves like those in Fig. 1, drawn to a large scale. Our diagrams easily gave an accuracy of a single thermal unit. To get the increase of entropy due to superheating, the function $\frac{c_p}{T}$ was computed for a sufficient number of temperatures and a new series of curves was drawn. Running the integraph over these curves gave the desired property.

7 To show the practical effect of the discrepancy between the results obtained by Professor Thomas and by Knoblauch and Jakob, a curve of the nature just described was determined from the tests of the latter at 100 pounds absolute and integrated in the same way. A small section of the two curves is shown in Fig. 2, drawn to a large scale, at the maximum deviation. This maximum deviation is 0.004 of a unit of entropy, the entropy due to superheating from Professor Thomas' work being 0.121; but this increase of entropy in practice is always used in conjunction with the entropy of the liquid and the entropy of vaporization, which quantities at 100 pounds are 0.4743 and 1.1227 respectively; the total increase above freezing point is consequently 1.5970, and it is with this latter quantity that the discrepancy should be compared. Such a comparison shows that the discrepancy amounts to one in four hundred, which must be considered to be eminently satisfactory. It should be specifically stated that I am not attributing such a degree of error to Professor Thomas' work which must be judged by itself, and which needs no commendation from me.

8 If it be permitted, I would like to state the purpose I had in view in my use of Professor Thomas' work, which was the preparation of a temperature-entropy table which should give the properties of steam, both saturated and superheated, at each degree fahrenheit from 80 to 420, and at each hundredth of a unit of entropy.

9 The properties given in the table are:

a *The quality.* For saturated steam this is usually represented by x_1 and is that proportion of the mixture which is steam. For superheated steam it signifies the superheating.

b *The heat contents.* Using r and q to represent the heat of vaporization and the heat of the liquid, and c_p for the specific heat, this property is represented by

$$x\,r + q \quad \text{for saturated steam}$$

$$xr + q + \int c_p dt \quad \text{for superheated steam.}$$

c *The specific volume.* This table was made primarily for our own use at the Massachusetts Institute of Technology, especially for teaching turbine design, and it is hoped that it will prove useful to others.

Mr. J. A. Moyer Professor Thomas' values for the mean specific heat of superheated steam at constant pressure, as now reported, agree, in some cases, almost exactly with those of Knoblauch and Jakob. I have prepared typical curves showing comparative values and find for superheats less than 270 degrees fahrenheit, and pressures ranging from 100 pounds per square inch to 200 pounds per square inch, where the specific heat of superheated steam at constant pressure enters as a factor, engineers may adopt, without appreciable error, either set of results. These remarks, it should be noted, are intended to apply only to the mean specific heat values.

2 Marked differences, not so much in actual values as in shape of curves, are observed between the curves of Knoblauch and Jakob, and those given by Professor Thomas above 250 degrees fahr. superheat. Professor Thomas' values are represented by practically straight lines with constantly decreasing values in the region of high superheats, while curves of mean superheat prepared by others, as those by Sugden from Knoblauch and Jakob's results give minimum values at from 200 to 400 degrees fahr. superheat, depending on the pressure. We have no means of knowing definitely which results are the more nearly correct, but as this is a disputed point, referred to by Professor Thomas in his paper, I wish to add something that to me appears to be very significant.

3 I have shown in calculations, published in the London Mechanical Engineer, of August 24, 1907, involving the impulse force of jets of superheated steam and using most recent and reliable data for the *flow* of superheated steam in nozzles, that the specific heat at constant pressure has a minimum value. In other words, this evidence confirms the observations of Knoblauch and Jakob, that:

a Values of the specific heat of superheated steam at constant pressure have a minimum value for any given pressure; and

b That if the temperature is increased beyond that corresponding to the minimum, values of the specific heat are increased.

4 It is also observed that if Professor Thomas' 300 pound line of *true* specific heat is extended in the direction he has drawn it, we shall have at 600 degrees fahr. of superheat a remarkably low value of about 0.45.

5 For the values of the specific heat of superheated steam at high pressures, the values of Knoblauch and Jakob agree much better with those of other recent observers including Callendar, Linde, and Lorenz than with those of Professor Thomas.

Finally, I may summarize:

a That the results given in this paper may be accepted by engineers generally for pressures from 100 pounds to 200 pounds per square inch without serious error.

b That compared with the results by other experimenters the results for high pressures apparently are not so well established.

c That because very high temperatures and superheats above 270 fahr. were not included in these data, they can scarcely be used to prove that the specific heat does not reach a minimum value, as shown by the very careful work of other experimenters.

Mr. A. R. Dodge The paper by Professor Thomas shows a marked advance in the method of determining c_p by electrical methods. There are several points concerning which the writer is in doubt which can probably be explained by the author.

2 Referring to Par. 52 and Fig. 19, it should be noted that the values of total heat for saturated steam are from steam tables. These values are not thought to be sufficiently accurate to determine the constant heat curves *BB*.[1] As a slight error in the total heats of saturated steam causes a marked change in the characteristics of these constant heat curves, irregularities in the curves *BB*, Fig. 19, are not conclusive. Even if we assume the values of total heat from steam tables to be correct, the black points mentioned in Par. 36 show reversed curvature at high total heats.

3 It is not clear whether the cold end of the thermo couple was kept at exactly constant temperature. Similar measurements of steam temperature by the writer show errors, unless each element of the thermo couple extends in one piece to the cold end, or unless the junctions between the couples and the extension piece to the cold end are sufficiently remote to prevent heat reaching them from the hot end by conduction.

4 Taking the mean values of c_{p2} at 15 lb. absolute, given by Professor Thomas for different degrees of superheat in Fig. 7, and multiplying these values by the ratios $\frac{c_{p1}}{c_{p2}} = \tan. \alpha$ found by the writer between 590 lb. absolute and 15 lb. absolute, we obtain mean values of c_{p1} for 590 lb. absolute. These are compared in the

[1]Peake, Proceedings of Royal Inst., June 28, 1905, p. 201. Denton, Stevens Indicator, October 1905, p. 383.

TABLE NO. 1

COMPARISON OF SPECIFIC HEATS AT THE SAME TOTAL HEAT

1 Total heat value	2 Superheat at 15 lb. abs.	3 Mean c_p at 15 lb. abs., Thomas	4 Corresp. superheat at 590 lb. using throttling calorimeter	5 Mean c_p at 590 lb. abs., Thomas	6 Mean c_p values substituting Col. 3 (c_{p_2}) in equation $\frac{c_{p_1}}{c_{p_2}} = \tan. \alpha$
A	0	.657			
B	25	.559			
C	50	.530			
D	100	.507			
E	150	496	17	.691	.682
F	200	.491	55	.635	.676
G	250	.487	92	.613	.670
H	300	.485	129	.598	.667
I	350	.483	169	.586	.665

TABLE NO. 2

COMPARISON OF SPECIFIC HEATS AT THE SAME SUPERHEAT. DERIVED FROM TABLE NO. 1

1 Superheat deg. fahr.	2 Mean c_p values 15 lb. abs., Thomas	3 Mean c_p values 590 lb. abs., Thomas	4 Mean c_p values substituting Col. 2 (c_{p_2}) in equation $\frac{c_{p_1}}{c_{p_2}} = \tan. \alpha$
0	.657	.840	.686
50	.530	.639	.677
100	.507	.609	.670
150	.496	.591	.666
200	.491	.578	.663
250	.487	.567	.661
300	.485	.559	.660

preceding tables with the values determined by Professor Thomas and are seen to differ considerably.

5 The radical difference between the present values of c_p given by Professor Thomas and those published by Professor Carpenter in November 1906,[1] using the same general method, as well as the marked discrepancy between all authorities, emphasizes the desirability

[1] Steam Plant of the White Motor Car, Vol. 28 Trans. A.S.M.E.

of a thorough investigation of the specific heat Society which should include a complete revis tables.

DR. SANFORD A. MOSS Professor Thomas is t on the completion of this work over which he ha long and patiently. I understand this is a fi of the work, superseding previous preliminary re ing is my understanding of the method by which obtained. I would like to inquire if this is correct

2 Fig. 9 represents the final set of experiments lent to some others and taken as exactly representi mental work. Fig. 16 gives the same values, witl scale. The values of Fig. 16 for zero pounds are ess of fairing. If there were any sudden chang very small pressures, the exact intersections wit pounds pressures would not be correct. By pl values given on a vertical line in Fig. 16 against 17 was obtained. The figures on the curves in represent degrees of superheat. The ordinates give total heat of superheated steam above saturat the actual or intrinsic energy present in the steam, nal work done by change of volume at constan and 6 are obtained by drawing tangents to the curves of Fig. 17 or by some process equivalent to shown that specific heat at some constant pressu of total heat. Fig. 7 and 8 were obtained from ordinates by abscissae. In drawing the Mollier di would like to inquire if Professor Thomas has a well-known formula for total heat of saturated ste

$$\lambda = 1091.7 + 0.305 \ (t - 32)$$

3 I have heard some doubt expressed as to tl formula. As I understand it, Professor Thomas' completely give the total heat of superheated ste 32 deg. since they give no information or ind the total heat of vaporization, but only give total zation point.

4 The method which Professor Thomas uses heat for zero pressure indicates that it is variable. although not positive theoretical reasons, for believ

heat of any gas at zero pressure is constant for all temperatures and is equal to the theoretical value given by molecular weight in comparison with hydrogen. Furthermore, the lowest pressure for which Professor Thomas took observations, seven pounds, is not very nearly zero pressure.

5 There is a vast difference between pressures which are practically zero and seven pounds pressure, as may be seen from the corresponding differences of volume. For instance, the volume at 0.07 lb. pressure is about one hundred times the volume at seven pounds pressure. The volume at 0.0007 lb. pressure is about ten thousand times the volume at seven pounds pressure. It seems to me that vast differences in total heat can occur under such circumstances.

6 In Par. 3 of his discussion, Mr. J. A. Moyer makes some remarks on calculations of specific heat of superheated steam from laws of impulse force of jets of superheated steam.

7 The writer has done a great deal of work in this direction, and has found that the impulse force of a jet of superheated steam, while directly dependent upon specific heat, changes very little for different values of specific heat. Therefore, a law for impulse force, while it may be *almost* exactly correct, will nevertheless give erroneous values of specific heat.

8 Laws of impulse derived from observation are, of course, subject to slight errors and hence can never give reliable values of specific heat. In other words, impulse force is such a slowly changing function of specific heat that it is not legitimate to use values of the function for exact determination of specific heat.

9 Computations in the inverse way; that is, calculation of impulse force laws from values of specific heat, show that wide differences in specific heat give insignificant changes (within the limit of observational errors) in impulse force laws. Hence conclusions regarding specific heat derived from impulse laws cannot be depended upon.

MR. J. A. MOYER Dr. S. A. Moss criticises the statement which I made in my previous discussion that calculations based on the laws of impulse force of jets and the flow of superheated steam from nozzles, as published in my paper in the Mechanical Engineer,[1] showed that the specific heat of superheated steam at constant pressure has minimum values.

2 In bringing into the discussion the probable value of experimental data of impulse force, he opens up a subject which we have often dis-

[1] Mechanical Engineer, Manchester, England, Aug. 24, 1907, p. 276–278.

cussed before and about which we are agreed. . he criticises, I stated plainly that the results, so f impulse force, were not based on experimental d thermodynamic relations."

3 Even if experimental work on the impulse fc used to determine anything regarding the specific steam, it does not show that deductions from la obtained by other methods; or by calculations fr dynamic relations are not valid.

4 In my general conclusion that the specific steam has minimum values, I am supported b Professor Heck[1] in his paper on The Thermal heated Steam, presented at the Detroit Meeting.

The Author The following statements are some questions in the foregoing discussion.

2 The values given by the curves of total steam include the total heat of saturated steam a nary steam tables based upon Regnault's de highly desirable that new determinations of h should be made, in order to test the accuracy of e:

3 In measuring steam temperatures, the colc was kept in melting ice, in a Dewar bulb, the duced directly into the steam, as shown in Fig. 3,

4 Fig. 5, 6, 7 and 8 indicate that the specific tically constant at zero pressure, as suggested by near the saturation point.

5 Fig. 9 is to be regarded as representing the results of these experiments. A study of Fig. 1(the experiments there represented were made sented in Fig. 9, and while less regular than the tive in all respects of the final results in Fig. experiments recorded in Fig. 9 were made the perfected to such an extent and such skill in attained, that the curves given in Fig. 9 cou reproduced at will, and the same results obtai The introduction of the independently heated a insulation about the calorimeter proved to be t in order to obtain the regular results shown in Fig

6 In all specific heat of steam experimen heated calorimeters, of which the writer has l

[1] Proceedings, May, 1908, p. 543-545.

exception of those which yielded the results given in this paper, the question as to the external work done by the steam in expanding through a calorimeter has required consideration. This was true of the first experiments made by the writer, but the difficulty of dealing satisfactorily with this question led to the method finally adopted, of using only one thermometer, in a fixed position, upon which both initial and final temperatures were measured. The method of doing this is described in Par. 21 to 28.

7 The slightest change in the quality of the steam entering the calorimeter is detected with ease, as described in the paper. A constant weight of steam is passing per unit of time, and being dried and then superheated to a given temperature by a constant electrical input of energy. If the amount of evaporation required varies in the slightest degree the temperature to which superheating takes place changes with the change in quality. The question of initial quality of the steam is thus effectually disposed of.

8 The method of making computations from the data given in Table 1 is fully set forth in Par. 59. These computations have been made with the greatest care, have been repeatedly checked and the results plot into the smooth curves shown in Fig. 9.

9 A careful reading of the paper will show the relation between the curves in Fig. 10 to 14, and Fig. 9, and the value of Fig. 10 to 14, in corroborating the curves in Fig. 9.

10 The writer trusts that this closure will answer the most important of the questions which have been asked concerning the paper.

No. 1179

DESIGN OF ENGINES FOR THE USE OF HIGHLY SUPERHEATED STEAM

By MAX E. R. TOLTZ, ST. PAUL, MINN.

Member of the Society

The value of superheated steam and the difficulties encountered in the installation of superheaters in stationary steam plants can be understood more readily by indicating in a brief way the difference between superheated and saturated steam.

2 Saturated steam is steam generated in the steam or water space of the boiler from which in such condition with certain tensions no heat can be abstracted without a percentage of condensation.

3 Superheated steam is a gas which can be expanded adiabatically to its saturation temperature without being liquefied.

4 Loss of heat in the pipes from the boiler to the steam engine and in the steam engine itself is unavoidable, and therefore a certain part of the saturated steam will condense in those places. This condensation will be in proportion to the moisture contained in the steam. The condensed steam not only does no work, but acts as a hindrance in the steam cylinder. On the other hand if the steam is superheated every particle of water contained in the wet steam will be evaporated.

5 By superheating the steam 200 degrees fahr. above its temperature, its volume increases, owing to pressure, about 25 per cent, which augmentation not alone gives more steam, but also reduces the influence of clearance in the cylinder, because superheated steam is more elastic than saturated steam.

6 Wilhelm Schmidt, the well known German engineer, has found the best way for the production of this highly superheated steam and he was the first to design and build engines adapted for its use. The hope cherished by Schmidt with the introduction of superheated steam was that by means of it the degree of efficiency of the "Carnot" cycle could be attained in an engnie, but in the course of his experi-

Presented at the New York Meeting (December 1907) of The American Society of Mechanical Engineers and forming part of Volume 29 of the Transactions.

ments, it was shown that the practical value of superheated steam rested only on the fact that condensation in the cylinder could be eliminated. It seems that these experiments were not carried on far enough, because according to Garbe (The Locomotives of the Present, 1906, page 223), later tests made by other authorities mentioned elsewhere in this article established quite a high economy in heat units with the use of superheated steam, which is expressed in the following diagram:

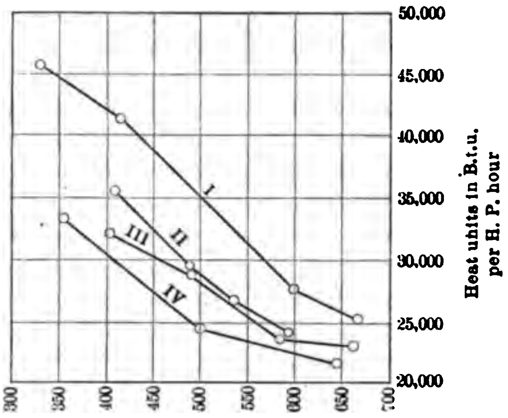

FIG. 1

Engine type	Cylinder diameter (inches)	Stroke (inches)	R.p.m.	Mean indicated h. p.	Tests made by	Tests carried out with
I	7.1+7.1	11.8	175	16.5	Ripper	Same h. p.
II	12.6	13.8	210	74.4	Doerfel	Same cut-off.
III	9.85	15.7	150	41.25	Seeman	Variable load
IV	9.45	29.5	95	39.4	Gebr. Sulzer	Same i.h.p.

7 At any rate, highly superheated steam having a temperature of from 575 degrees to 625 degrees fahr. should be used to secure the benefit of steam and coal saving, but this can be accomplished only when the steam engine is designed for the high temperatures of such steam, and it will therefore be necessary to remodel our present engines.

8 Before going into the details of such changes, the writer submits three tables showing the steam and coal economy of different types

STEAM AND COAL SAVING IN A TRIPLE EXPANSION ENGINE CONDENSING, OF 5000 I.H.P. WITH SUPERHEATED STEAM AT DIFFERENT TEMPERATURES

PRESS. 14 ATM. = 199 LB.; TEMP. OF SAT. STEAM 381 DEG. FAHR.; CUT-OFF 4 PER CENT.; PISTON SPEED 16.5 FT. PER SEC.;

AUTOMATIC CUT-OFF; 4 POPPET OR PISTON VALVES PER CYL.

CONDITIONS	KIND OF SUPERHEATER	DEGREES OF SUPERHEAT	TEMPERATURE OF STEAM	CUT-OFF CONSTANT I.H.P. VARIABLE PROF. HRABAK'S RESULTS							CUT-OFF VARIABLE. I.H.P CONSTANT MR. TOLTZ'S COMPUTATION							
					AT ENGINE			AT BOILER					AT ENGINE			AT BOILER		
				I.H.P.	Steam consump. per i.h.p. hour lb.	Saving over sat. steam: Steam per cent	Saving over sat. steam: Fuel per cent	Feedwater per i.h.p. hour in lb.	Saving over sat. steam: Feed-water percent	Saving over sat. steam: Fuel per cent	I.H.P.	VARIATION OF CUT-OFF per cent	Steam consump. per i.h.p. hour in lb.	Saving over sat. steam: Steam percent	Saving over sat. steam: Fuel per cent	Feedwater per i.h.p hour in lb.	Saving over sat. steam: Feed-water per cent	Saving over sat. steam: Fuel per cent
		deg. fahr.	deg. fahr.															
Saturated Steam.....	NONE...............	0	381	5000	11.82	—	—	12.70	—	—	5000	4.00	11.82	—	—	12.70	—	—
Low Superheat 75 to 150 deg. fahr.	Attached to boiler....	144	525	4350	10.50	11.5	7.5	10.70	16	12	5000	4.85	10.90	7	3.0	11.25	11.5	7.5
	Separately fired......	144	525	4350	10.50	11.5	−3.0	10.70	16	2	5000	4.85	10.90	7	−8.0	11.25	11.5	−2.5
Medium Superheat 150 to 225 deg. fahr.	Attached to boiler....	216	597	4150	9.81	17.0	10.0	10.03	21	17	5000	5.15	10.32	13	6.0	10.52	17.5	11.0
	Separately fired......	216	597	4150	9.81	17.0	0.0	10.03	21	8	5000	5.15	10.32	13	−4.5	10.52	17.5	1.0
	Steam through attached superheater and afterward through separately fired superheater	216	597	4000	9.15	22.5	12.5	9.35	26	19	5000	5.40	9.60	19	8.5	9.80	23.0	13.5
	Steam through separately fired superheater and afterward through attached superheater	216	597	4000	9.15	22.5	11.0	9.35	26	17	5000	5.40	9.60	19	6.5	9.80	23.0	12.0
High Superheat 255 to 290 deg. fahr.	Attached to boiler....	288	669	4000	9.15	22.5	13.0	9.35	26	21	5000	5.40	9.60	19	9.0	9.80	23.0	14.0
	Separately fired......	288	669	4000	9.15	22.5	4.0	9.35	26	12	5000	5.40	9.60	19	−1.0	9.80	23.0	5.0
	Steam through attached superheater and afterward through separately fired superheater	288	669	3775	8.48	28.0	16.0	8.70	31	24	5000	5.85	9.20	22	9.0	9.40	26.0	14.5
	Steam through separately fired superheater and afterward through attached superheater	288	669	3775	8.48	28.0	14.5	8.70	31	22	5000	5.85	9.20	22	7.5	9.40	26.0	13.0
Very High Superheat 290 to 360 deg. fahr.	Attached to boiler....	353	734	3775	8.48	28.0	18.0	8.70	31	25	5000	5.85	9.20	22	11.5	9.40	26.0	16.5
	Separately fired......	353	734	3775	8.48	28.0	8.0	8.70	31	16	5000	5.85	9.20	22	1.5	9.40	26.0	7.0

of engines with the application of superheated steam of different temperatures. The results given were compiled by Professor Hrabak, Prague, Bohemia, and the writer has enlarged upon them by computing the variable cut-offs to maintain the same power output with

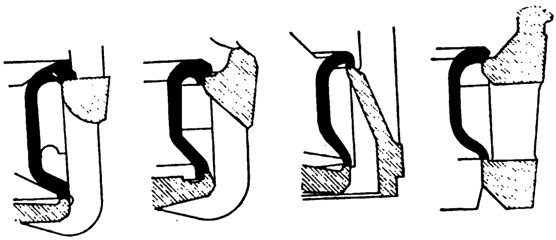

FIG. 2 TYPES OF DOUBLE SEATED POPPET VALVE

the same cylinder dimensions. Attention is called to the low economy of fuel saving with a separately fired superheater when compared with one placed within the boiler setting, or what is known as the attached type of superheater.

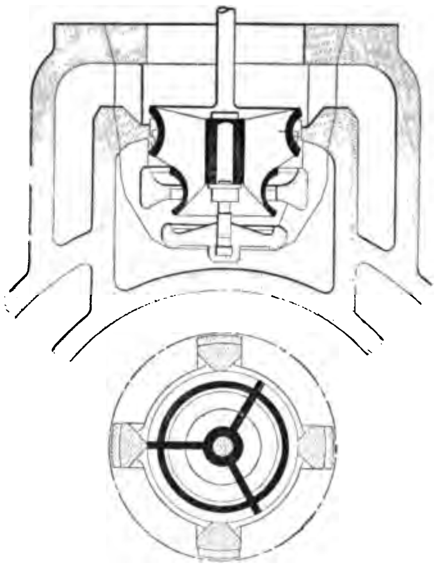

FIG. 3 FOUR SEATED POPPET VALVE

9 It is not in the province of this paper to discuss superheaters proper, but their principal feature may be mentioned, which is that a superheater should transmit the highest number of heat units per square foot of heating surface per hour for one degree temperature difference.

THE DESIGN OF ENGINES FOR HIGHLY SUPERHEATED STEAM

10 The Corliss valve which has given satisfactory results in saturated steam practice cannot be applied for a steam of very high temperature on account of its large wearing surface, which is difficult to lubricate because it expands by reason of the high heat of the steam and gives serious trouble by sticking.

11 It is generally conceded that a superheat of from 100 degrees to 120 degrees fahr. with a temperature of the steam of not more than 475 degrees fahr. at the valve is allowable for a Corliss valve. Yet the writer knows of one case in which the temperature was 497 degrees fahr. This is not high enough, especially in high duty engines, to obtain high economies; therefore, with the use of highly

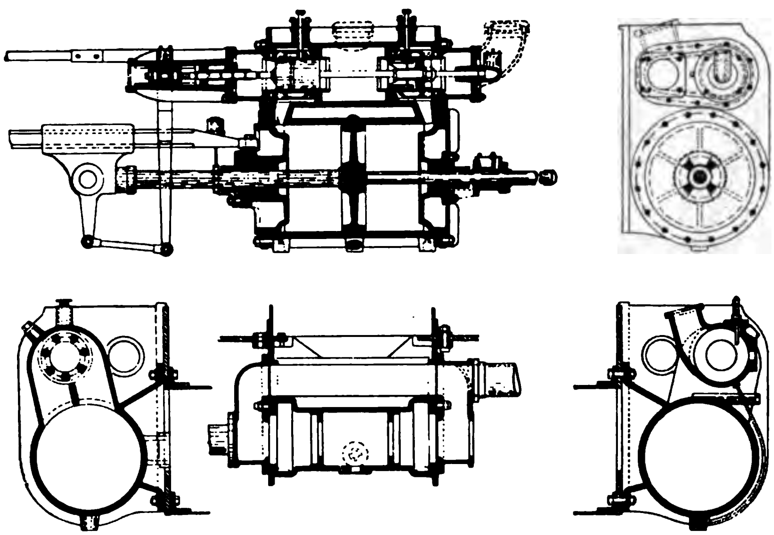

FIG. 4 SOLID PISTON VALVE SCHMIDT

superheated steam as referred to above, it is necessary to replace the Corliss valve by double seated poppet valves for engines of moderate size and slow piston speed and, for large engines of high piston speeds, by four seated poppet valves. It is also advisable to apply piston valves. The illustration, Fig. 4, shows the "Schmidt" solid piston valve which has the interesting feature of being jacketed by superheated steam. The other valve, Fig. 5, used in Belgium mostly, has one solid ring with several grooves and small holes for the purpose of leading any steam that may leak through from the admission side to the back of the ring, so enabling it to act as a spring thus giving it closer contact. One or four of either type of valve for one cylinder may be used to effect the distribution of steam.

12 It is advantageous to locate the valves in the cylinder heads in order to get a very plain cylinder in the form of a straight pipe. The cylinder can be made very plain as a steam jacket is not necessary for the high pressure cylinder, while for the low pressure, a jacket may be applied. The material of the cylinder should be distributed uniformly to prevent warping due to the high temperatures.

13 For horizontal tandem type engines the low pressure cylinder should, whenever possible, be located on the frame and the high

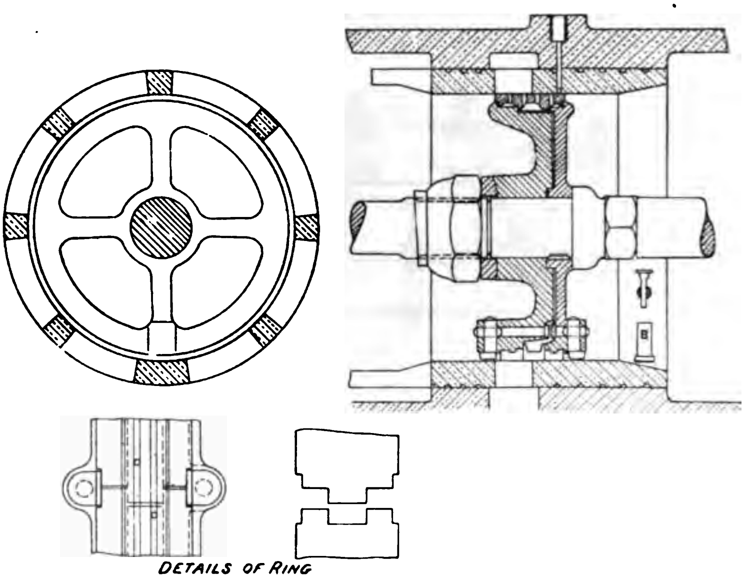

FIG. 5 BELGIAN PISTON VALVE

pressure cylinder in the rear, which arrangement will at the same time reduce any heating in the cross head guides.

14 The tandem type is recommended because it works the engine with high piston speed which means low first cost of the engine.

15 Although it is generally understood that poppet valve engines can run only at about 120 to 150 r.p.m., the latest types in Europe are designed for 230 to 240 r.p.m., while in this country they are now being built for any speed up to 300 r.p.m. The writer has so far not been able to corroborate the latter statement, which was made during the Indianapolis Meeting of the Society.

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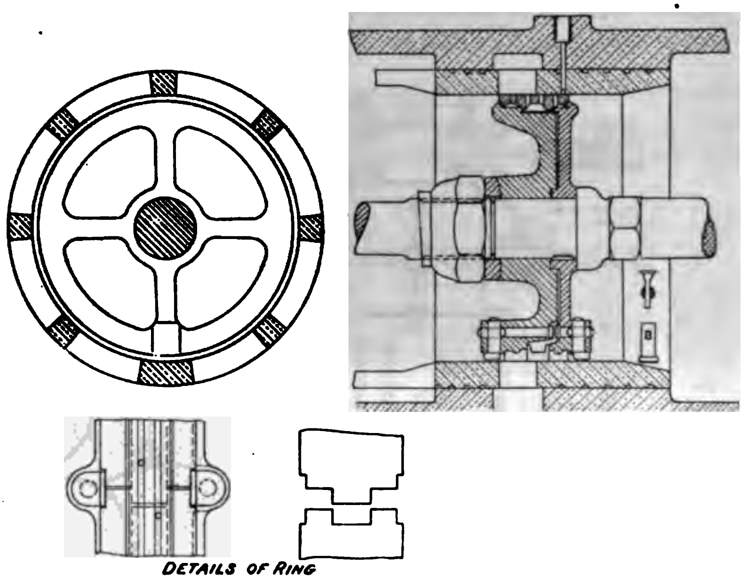

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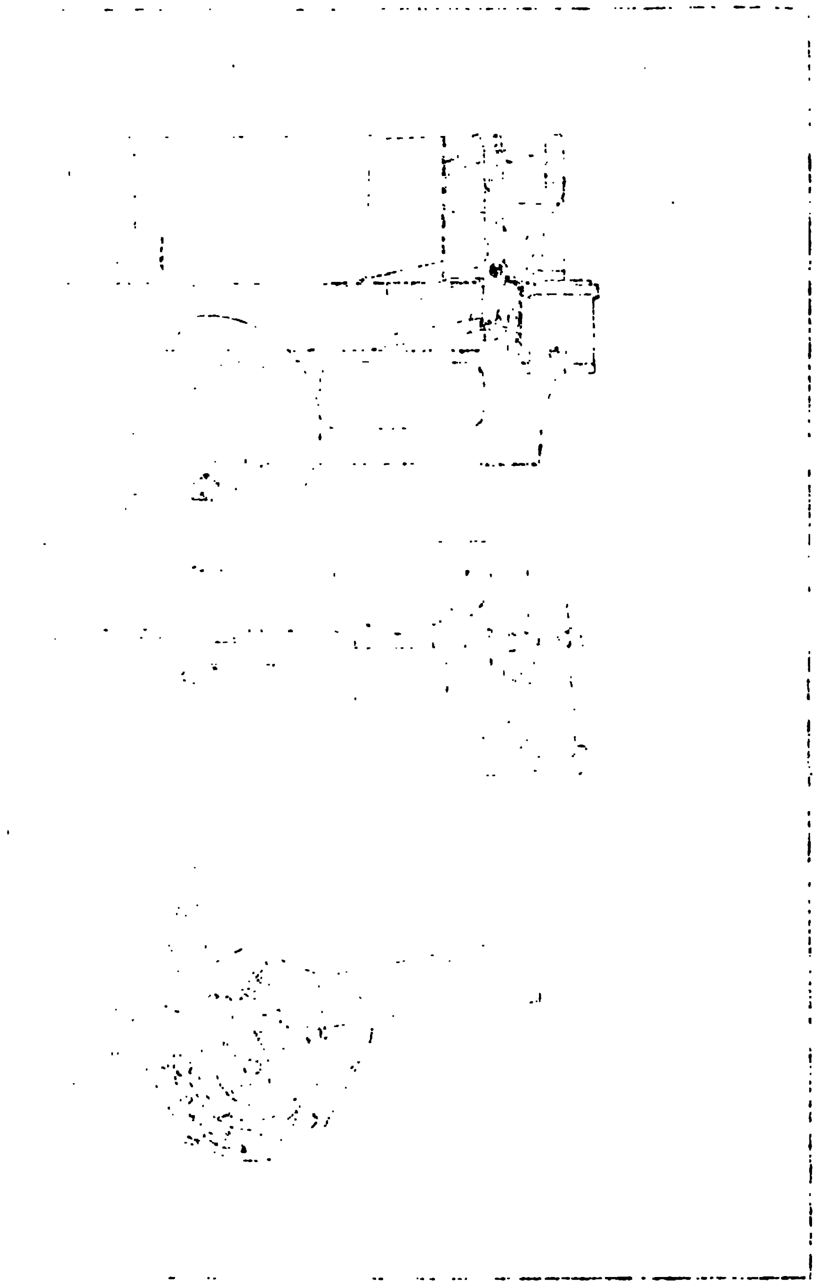

16 If valve casings are cast on the cylinder, it should be done in a very plain manner, but no steam channels should be cast on in connection therewith. Each valve casing should be provided with a flange to make pipe connection for admission as well as exhaust steam.

17 The piston should have at least three rings of good width. For horizontal engines it should be guided outside of the cylinder by the cross head and an extra liberal bearing for the extended piston rod so that the piston body will not ride on the cylinder wall.

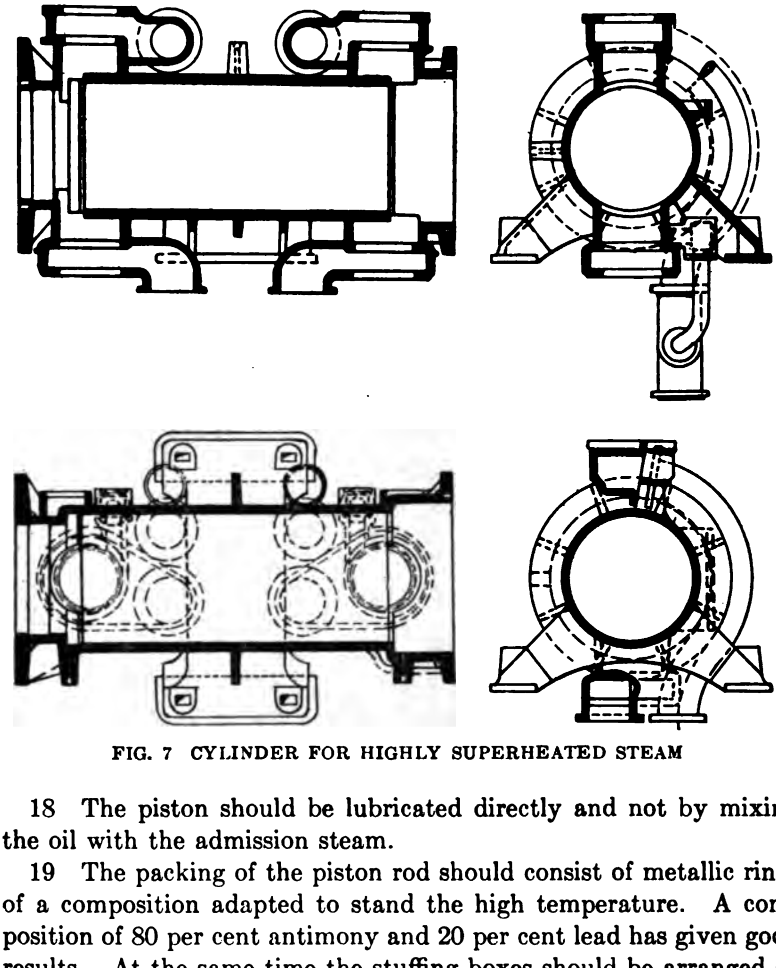

FIG. 7 CYLINDER FOR HIGHLY SUPERHEATED STEAM

18 The piston should be lubricated directly and not by mixing the oil with the admission steam.

19 The packing of the piston rod should consist of metallic rings of a composition adapted to stand the high temperature. A composition of 80 per cent antimony and 20 per cent lead has given good results. At the same time the stuffing boxes should be arranged so as to offer plenty of cooling surface to the outside air in order to reduce the temperature.

TABLE 2

STEAM AND COAL SAVING IN A COMPOUND ENGINE, CONDENSING, OF 250 I.H.P. WITH SUPERHEATED STEAM AT DIFFERENT TEMPERATURES

PRESS. 10 ATM. = 142.23 LB.; TEMP. OF SAT. STEAM 354 DEG. FAHR.; CUT-OFF 6 PER CENT; PISTON SPEED 10 FT. PER SEC.; AUTOMATIC CUT-OFF; 4 POPPET OR PISTON VALVES PER CYL.

CONDITIONS	KIND OF SUPERHEATER	DEGREES OF SUPERHEAT	TEMPERATURE OF STEAM	CUT-OFF CONSTANT. I.H.P. VARIABLE PROF. HRABAK'S RESULTS							CUT-OFF VARIABLE. I.H.P. CONSTANT MR. TOLTZ'S COMPUTATIONS							
					AT ENGINE			AT BOILER					AT ENGINE			AT BOILER		
				I.H.P.	Steam consump. per i.h.p hour lb.	Saving over sat. steam: Steam per cent	Saving over sat. steam: Fuel per cent	Feedwater per i.h.p. hour lb.	Saving over sat. steam: Feed-water p.c.	Saving over sat. steam: Fuel per cent	I.H.P.	VARIATION OF CUT-OFF Per cent	Steam consump. per i.h.p. hour lb.	Saving over sat. steam: Steam per cent	Saving over sat. steam: Fuel per cent	Feedwater per i.h.p. hour lb.	Saving over sat. steam: Feed-water per cent	Saving over sat. steam: Fuel per cent
		deg. fahr.	deg. fahr.															
Saturated Steam	NONE	0	354	250	14.72	—	—	15.73	—	—	250	6.00	14.72	—	—	15.73	—	—
Low Superheat 75 to 150 deg. fahr.	Attached to boiler	130	484	225	12.25	15.0	11.0	12.50	21	17	250	6.95	12.50	15.0	11.5	12.70	20.0	16.0
	Separately fired	130	484	225	12.25	15.0	1.5	12.50	21	8	250	6.95	12.50	15.0	1.5	12.70	20.0	7.0
Medium Superheat 150 to 225 deg. fahr.	Attached to boiler	202	556	215	11.60	21.0	15.0	11.81	25	21	250	7.50	11.75	20.0	14.0	11.98	24.5	18.5
	Separately fired	202	556	215	11.60	21.0	5.5	11.81	25	12	250	7.50	11.75	20.0	4.5	11.98	24.5	9.5
	Steam through attached superheater and afterward through separately fired superheater	202	556	205	10.70	27.5	18.0	10.93	31	24	250	8.00	10.85	26.0	17.0	11.09	30.0	21.0
	Steam through separately fired superheater and afterward through attached superheater	202	556	205	10.70	27.5	16.5	10.93	31	23	250	8.00	10.85	26.0	15.0	11.09	30.0	19.5
High Superheat 225 to 290 deg. fahr.	Attached to boiler	274	628	205	10.70	27.5	19.0	10.93	31	27	250	8.00	10.85	26.0	17.5	11.09	30.0	21.5
	Separately fired	274	628	205	10.70	27.5	10.0	10.93	31	17	250	8.00	10.85	26.0	8.5	11.09	30.0	13.0
	Steam through attached superheater and afterward through separately fired superheater	274	628	198	10.27	30.0	18.5	10.50	34	26	250	8.50	10.51	28.5	16.0	10.75	32.0	20.5
	Steam through separately fired superheater and afterward through attached superheater	274	628	198	10.27	30.0	17.0	10.50	34	25	250	8.50	10.51	28.5	15.0	10.75	32.0	19.0
Very High Superheat 290 to 360 deg. fahr.	Attached to boiler	338	692	198	10.27	30.0	20.5	10.50	34	28	250	8.50	10.51	28.5	18.5	10.75	32.0	22.5
	Separately fired	338	692	198	10.27	30.0	11.5	10.50	34	20	250	8.50	10.51	28.5	9.0	10.75	32.0	13.5

20 The cylinder dimensions of the saturated steam engine are based upon an economical cut-off, and the reduction of this cut-off is limited by the increasing condensation which takes place when the

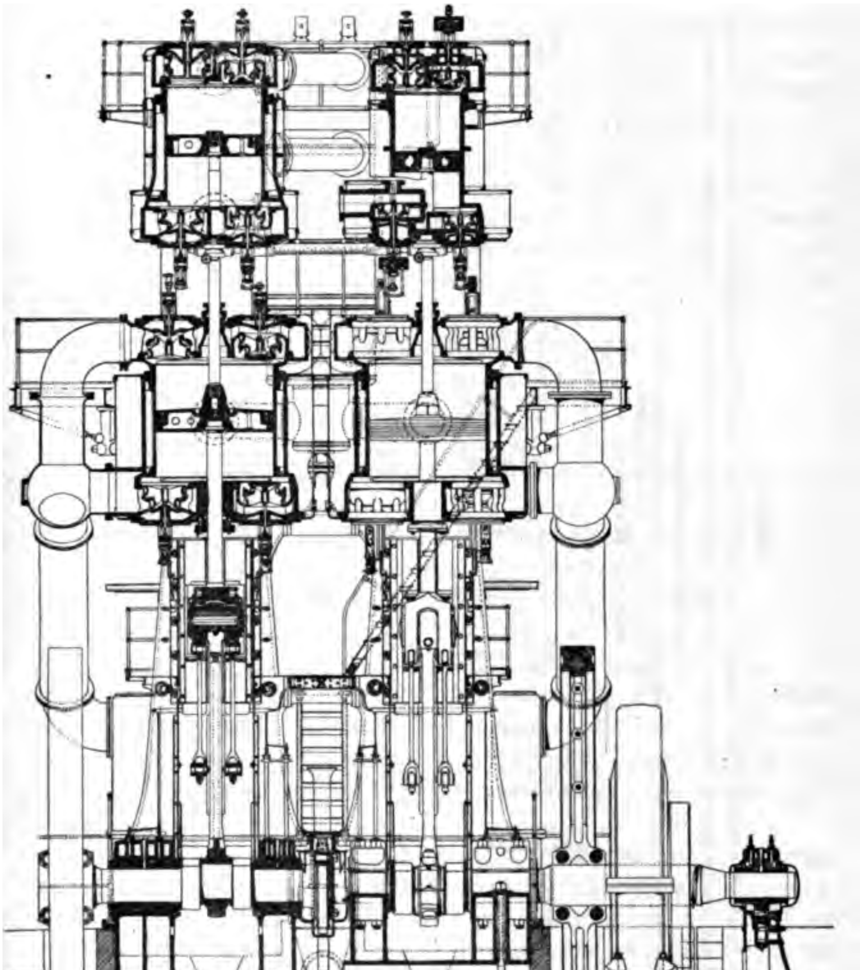

FIG. 8 3000 H. P. INSTALLED AT ELECTRICAL WORKS, BERLIN. BUILT BY SULZER BROS.

cut-off is decreased beyond a certain minimum. To improve this feature, the compound, triple and quadruple expansion engines have been introduced; in which, on account of the smaller temperature

TABLE 3

Steam and Coal Saving in a Simple-Noncondensing Engine of 250 I.H.P. with Superheated Steam at Different Temperatures

Press. 12 atm = 177 lb.; temp. of sat. steam 369 deg. fahr.; cut-off 20 per cent; piston-speed 10 ft. per sec.; slide or piston valve; change of cut-off effected by valve gear

Conditions	Kind of superheater	Degrees of superheat	Temperature of steam	Cut-off constant. I. H. P. variable Prof. Hrabak's results							Cut-off variable. I.H.P. constant Mr. Toltz's computations							
					At engine			At boiler				At engine			At boiler			
				I.H.P.	Steam consump. per i.h.p hour lb.	Saving over sat. steam: Steam per cent	Saving over sat. steam: Fuel per cent	Steam consump. per i.h.p. hour lb.	Saving over sat. steam: Feed-water per cent	Saving over sat. steam: Fuel per cent	I.H.P.	Steam consump. per i.h.p. hour lb.	Saving over sat. steam: Steam per cent	Saving over sat. steam: Fuel per cent	Steam consump. per i. h. p. hour lb.	Saving over sat. steam: Feed-water per cent	Saving over sat. steam: Fuel per cent	
		deg. fahr.	deg. fahr.															
Saturated Steam.....	NONE................	0	369	250	27.00	—	—	29.00	—	—	250	27.00	—	—	29.00	—	—	20.00
Low Superheat 75 to 150 deg. fahr.	Attached to boiler....	103	472	235	21.00	22.0	18.5	21.40	27	23	250	21.05	22.0	18.5	21.47	26.0	22.5	20.88
	Separately fired	103	472	235	21.00	22.0	10.0	21.40	27	14	250	21.05	22.0	9.5	21.47	26.0	14.0	20.85
Medium Superheat 150 to 225 deg. fahr.	Attached to boiler....	162	531	230	19.85	26.5	20.5	20.10	30	27	250	20.00	25.5	20.0	20.40	29.5	24.0	21.35
	Separately fired......	162	531	230	19.85	26.5	21.5	20.10	30	19	250	20.00	25.5	11.0	20.40	29.5	15.5	21.35
High Superheat 225 to 290 deg. fahr.	Attached to boiler....	234	603	222	18.50	31.0	23.0	18.85	35	31	250	18.75	30.5	22.0	19.13	34.0	26.0	21.75
	Separately fired......	234	603	222	18.50	31.0	15.0	18.85	35	22	250	18.75	30.5	13.5	19.13	34.0	18.0	21.75

differences between the admission and the exhaust steam in the different cylinders, condensation has been decreased materially.

21 In an engine for superheated steam, the degree of expansion can be brought to a higher state of perfection than in an engine for saturated steam because it is only a question of superheating the admission steam high enough to eliminate condensation entirely. Therefore, the cut-off should be reduced, but the cylinder dimensions should be enlarged in proportion in order to be equivalent in power to the saturated steam engine.

22 On existing engines the speed should be increased if it is mechanically possible. Although this change calls for higher steam velocities in the steam channels and valves it must be borne in mind that superheated steam can attain velocities from 40 per cent to 60 per cent greater than that of saturated steam without showing a throttling line of expansion on an indicator diagram.

DISCUSSION

Mr. H. Emerson It is somewhat ungracious when a member has been kind enough to present to us a table involving as much labor as the one by Mr. Tolz to cast doubt on the value of his conclusions. What leads me to do this is that during the last three years I have had charge of the records of over sixteen hundred engines on one of the largest transcontinental railroads. Many persons have suggested various operating economies. Most of them are theoretical rather than practical. Hence, when I see statements to the effect that the use of some particular kind of appliance, the use of some form of superheater has actually effected a saving in coal, or a saving in water, my past experience leads me to feel skeptical until practical results are shown.

2 Road engines in actual service will be charged on an average with 240 pounds of coal per 1000 ton miles. The same engine, on a measured test, will use 80 pounds of coal per 1000 ton miles. If an economy of 20 per cent is effected in road issues of coal, it must be about 48 pounds or 60 per cent of the coal actually required for steam. This is manifestly impossible.

Prof. F. R. Hutton It may be of interest to report an experience on an engine with a packless throttle valve and superheated steam. The inventor sought to make a diaphragm valve, the spindle of the valve being attached to a diaphragm of sufficient area so that there would be no resistance from the flexure.

2 The difficulty was found to be that the throttle valve spindle continuously lengthened under the exposure to the superheated steam; so that every once in a while, even if you started out with full adjustment, a time would come when you couldn't get that throttle valve to open because the spindle lengthened and closed the valve, so that while apparently from without it was in the position of being wide open, it was really nearly closed.

MR. H. H. SUPLEE Recently one of the most prominent builders of steam engines in Switzerland informed me his works were about to begin building engines for the use of superheated steam and they found that the Corliss valve gave them trouble.

2 He said he had practically decided that a steam engine for highly superheated steam should be designed with poppet valves, along the general lines of the gas engine and possibly for even higher temperatures as the use of cooling water is not permissible. Metal temperatures of 450 degrees fahr. and higher occur with superheated steam, and this is materially higher than the water-cooled cylinder of a gas engine. On account of the high degree of superheat often desired, the gas engine design may well be taken as a guide for suitable provision for the expansion of steam engine parts exposed to such a high temperature range. Under such high working temperatures the question of the molecular change of metals becomes very important and opens a wide field for investigation.

PROF. C. E. LUCKE As the commercial value of the steam engine, as well as of any other machine, depends more upon the cost side of the question than upon thermal efficiency, I should like to ask the author of this paper to present some data on how the cost of manufacture of this poppet valve engine would compare with our present standards.

2 I should also like to ask him to state how the cost of maintenance and lubrication would compare with the existing standard engines, and how the lubricating oil should be specified.

MR. R. T. ODE We probably have had as much to do with superheated steam engines as any other manufacturer in this country; we have at the Lancaster Railway Company's main central station, three 1500 h.p. superheated steam engines, one 600 h.p. cross compound engine at Millbourne Mills, a report upon which was presented to the Association by Professor Jacobus, and several others of from 500 to 1500 h.p.

2 Our experience has been that it is profitable to use a moderate degree of superheat in cases where service is continuous. This degree of superheat is not limited to any feature of design, but is because of the slight gain that can be obtained in the coal consumption. We found that high temperatures distorted the cast iron cylinders, and that it took about six weeks operation before the cylinders took final shape or set. In our designs we are very careful to leave nothing on the cylinder barrels that may cause unequal expansion or distortion.

3 We find that poppet valve engines cost about the same as the ordinary Corliss engines. If it were not for the fixed American ideas so favorable to the Corliss valve engine, we think many manufacturers of engines in this country would now be following the European practice, for the performance of the poppet valve engine is most satisfactory.

4 In regard to the floor space and cost of the entire plant, we find that in the superheated steam installation the smaller quantity of steam required to develop the same power, as compared with the saturated steam engine, offsets the difference there is in the floor space and extra cost of the superheater, inasmuch as the boiler capacity required is less.

5 In regard to piping equipment, we find that the same features suggested in regard to the design of the cylinder apply here also. If we take care with design we have no trouble from distortion.

6 As we are the introducers of the Schmidt system in America, we are very much interested in the results shown in the table.

7 I notice there are three sheets of results given, and I do not know whether they are compiled directly from actual tests or tabulated from a few tests. I would like Mr. Toltz to tell us about that. I think these tables are of more value than anything else we have on the subject.

Mr. J. A. Seymour It seems very important to emphasize the fact, which is referred to only indirectly by the author of the paper, that the possible increase in economy from the use of superheated steam comes from two sources:

- *a* From the increase in range of temperature limits between which the engine works.
- *b* From the decrease in the amount of heat by-passed around the working cycle through heat transference to and from the cylinder walls.

2 This heat transference is called by the author "cylinder condensation," as is customary, but the term is misleading. What is meant

by "cylinder condensation" is condensation by reason of heat being given up by the steam to the cylinder walls during the early part of the stroke when the steam is hotter than the cylinder walls. Steam is also condensed at a later period during expansion in the cylinder in order to supply a sufficient heat equivalent to the work performed. This is not a source of loss of economy, but a gain, and in actual practice the more economical the engine, the greater the amount of condensed steam in the exhaust.

3 When the range between the high and low temperature limits in any heat engine is increased, conditions are secured which, with an ideal engine would give increased economy. Practically, there is only a comparatively small saving in the economy of the engine from this source when using a high degree of superheat which to many of us, does not seem to compensate for the resulting decrease in the efficiency and reliability of the remainder of the plant.

4 In regard to the saving from the second mentioned source, Professor Unwin pointed out, a good many years ago, that the effect of superheat in lessening the transfer of heat to the cylinder walls before expansion takes place and back again to the steam during the exhaust stroke, was very considerable for a comparatively small amount of superheat, but that, as the superheat was increased, the corresponding increase in this effect rapidly diminished and that the increased saving was not worth while for a superheat higher than from 100 to 120 deg. fahr.

5 One of the difficulties encountered with high superheat is cylinder lubrication. With moderate superheat there seems to be no greater difficulty in this respect than with saturated steam and perhaps, on the average, rather less difficulty. When you have very wet steam, especially with bad feed water, there will be more trouble with cylinder lubrication than with steam moderately superheated.

6 Valve troubles with superheated steam generally come from the distortion of the valve by reason of high temperature. Eight or nine years ago the regular form of unbalanced gridiron valve, such as was used on McIntosh & Seymour engines, was tested with highly superheated steam, with the expectation that some other form of valve should possibly be adopted where superheat was used. The test showed this type of valve to be suitable in every way for use with highly superheated steam. Since that time more than thirty engines put out with this type of valve and aggregating 75 000 h.p., are running with superheated steam, and no difficulties whatever have developed. In none of these engines has the superheat been higher than 125 deg. for the reason, as explained above, that it was not thought

that there would be any practical gain, all things being considered, by increasing the superheat above this point. With this degree of superheat no troubles nor drawbacks whatever have been experienced, either in the engine or elsewhere in the steam plant.

7 One of the principal reasons why these gridiron valves have given no trouble with superheated steam is that the seats are very stiff and the valves themselves are comparatively limber, so that the form of valve will easily follow that of the seat in case of any change in shape due to the high temperature. With superheated steam it is of the greatest importance to adopt a form of valve which, if distorted by a high temperature, will not stick or leak, and it should not be assumed that the double poppet valve is the ideal valve for this service. There are two large power plants in New York, the Interborough and the Manhattan Elevated, where the engines in both stations were built by the same concern and are, in general, similar in all respects, except that in one station double poppet valves are used on the high-pressure cylinder, and in the other, ordinary Corliss valves. It is currently reported that the poppet valves are not as tight as the Corliss valves in the older station, and that the poppet valve engines do not give as good economy.

8 It is not fair to compare the performance of a Sulzer engine with that of the average American engine The Sulzer engine is built with a refinement of detail and a perfection of workmanship that would be commercially impossible in this country. This refinement makes possible a fine performance in spite of details, which, especially if designed for the usual conditions obtaining in power plants in this country, might be bettered. The writer greatly admires the Sulzer engine and its performance, but believes that it might give still better economy with some other form of valve.

9 The economy of an engine using superheated steam should not be given in pounds of coal which combines with the engine performance that of the steam generating and superheating part of the plant nor in pounds of feed water, for both methods make comparisons with other engines very misleading. It takes a good many more heat units to transform a pound of feed water into highly superheated steam than into saturated steam. The economy of the engine should be stated in terms of the number of thermal units added to the feed water per unit of work, in the manner recommended by the Committee on Tests of this Society. By this means the apparently large percentages saved by the use of highly superheated steam, on the pounds of feed water rating, will be very considerably reduced when the correct rating is used.

10 It is not possible to give examples of this from the author's paper, since in the tests quoted he does not give the vacuum. Below are comparisons from published tests of an engine, made both with saturated steam and with highly superheated steam, and also of another engine running with a moderate degree of superheat.

Pounds of steam per i.h.p. with 374.5 deg. superheat	9.56
Pounds of steam per i.h.p. with saturated steam	13.84
B.t.u. per i.h.p. per minute with 374.5 deg. superheat	203.7
B.t.u. per i.h.p. per minute with saturated steam	248.2
Apparent saving with 374.5 deg. superheat on basis of pounds of steam supplied to engine, per cent	30.9
Actual saving with 374.5 deg. superheat on basis of B.t.u. supplied to feed water, per cent	17.9
Pounds of steam per i.h.p. with 92.3 deg. superheat	11.21
B.t.u. per i.h.p. minute with 92.3 deg. superheat	209.6
Apparent saving with 374.5 deg. superheat compared with 92.3 deg. superheat on basis of pounds of steam supplied to engine, per cent	14.7
Actual saving with 374.5 deg. superheat compared with 92.3 deg. superheat on basis of B.t.u. supplied to feed water, per cent	2.8

11 These results are only intended to show the fallacy of making comparisons on the basis of economy ratings given in pounds of steam supplied to the engine, and they have no bearing on the comparative economy of the various degrees of superheat given, on account of the dissimilarity of the conditions in the tests quoted. The results are given on the basis of the Regnault valve of 0.48 for the specific heat. The comparative savings are only slightly affected if the more correct values of Professor Thomas are used.

MR. I. E. MOULTROP The temperature of the steam is one of the most important considerations in this discussion.

2 The writer had experience, for some ten or twelve years, with the use of superheated steam in large power plants. About 1896 the Edison Electrical Illuminating Company of Boston increased the capacity of one of their power plants. Four 400 h.p. Babcock & Wilcox boilers were installed in the fire room, equipped wth the Babcock & Wilcox attached type of superheater, designed for 125 deg. fahr. superheat. These were connected to the pipe mains already installed, in parallel with seven boilers of the same size without superheaters. In the engine room were some vertical triple expansion engines with piston valves, and one or two vertical compound engines of the type Mr. Seymour mentions, equipped with gridiron slide valves.

3 We did not know much about the use of superheated steam at that time, and made this installation partly as an experiment. We

expected to have some trouble with cylinder lubrication and also with packings, etc., but other than changing the grade of cylinder oil for one adapted to the higher temperature, which did not materially change the cost, none of the anticipated troubles developed.

4 Of course, with the small number of superheaters installed the total temperature of the steam at the engines was not very much in excess of the temperature for saturated steam at the boiler pressure.

5 During the next few years, eight similar boilers with superheaters and a few more vertical compound engines of the gridiron valve type, were installed at the station. The subsequent installations were made in such a way that boilers with superheaters were run separate from those without, so that the total temperature of the steam at the engines would run up to about 450 deg. fahr. This later installation has been in use seven or eight years, and we have yet to experience any of the anticipated troubles due to the use of superheated steam.

6 About five years ago we built a large turbine station using the same type of boilers and superheaters, except that here the steam pressure was 175 lb. and the superheaters built for 150 deg. fahr. of superheat. This nominally gives a temperature of steam of about 525 deg. fahr., but while the boilers are being forced during the peak of the load, the total temperature of steam probably reaches as high as 600 deg. fahr. at times.

7 We have found that under these conditions there are things to be watched. In some instances we believe we have found evidence of the deleterious effect of superheated steam on cast iron, which has been mentioned in the previous discussion, and we think the same may be true in a measure in reference to gun iron. We are also pretty well satisfied that brass or copper are not good materials to bring in contact with superheated steam. No special difficulty was encountered in the lubricating of the auxiliaries at this higher temperature, but there does seem to be a question as to whether there is any economy in carrying the superheat beyond this amount.

The Author The writer is pleased that this subject has aroused so great an interest, as shown by the discussion. In answer to several questions he can state that the tables regarding the economy of superheated steam were compiled from actual tests by Professor Hrabak.

2 The remarks regarding coal performance of locomotives made by Mr. Emerson are rather surprising. There is no doubt that better results can be obtained under test than in actual practice, but it should be borne in mind that the conditions differ in both cases. In

practice a locomotive may be out on a run for from 15 to 20 hours, while its actual, continuous work is only 8 to 12 hours. The balance of the time it is standing on side tracks, etc., which means that coal must be spent for non-productive work. But there is not one case to the knowledge of the writer in which there has been shown such difference in coal consumption, viz: 80 lb. against 240 lb. per 1000 ton miles.

3 Superheaters on locomotives in foreign countries have been a success during the last five years and in this country and Canada very fine results have been obtained. The Canadian Pacific has over 350 engines equipped, while in the United States only 22 are running, 7 of which the writer designed. The average saving of coal over the saturated steam locomotive on the Canadian Pacific is from 15 to 18 per cent, while on the Great Northern, 20 per cent has been recorded by the monthly performance sheet, yet in tests 28.4 per cent have been obtained.

4 The cost of manufacture of poppet valves and their maintenance has been fully answered by Mr. Ode.

5 Referring to lubrication, the oil which has given perfect satisfaction in stationary engines is Gargoyle-Hecla B, with a flashing point of 650 deg. fahr., manufactured by the Standard Oil Company, while on locomotives a similar product of the Galena Oil Company is being used. Although forced feed is recommended, the latest types of hydrostatic lubricators have done the work satisfactorily. The superheat on locomotives runs from 175 deg. fahr. to 250 deg. fahr., with a final temperature of the steam of from 550 deg. fahr. to 625 deg. fahr., without developing any difficulty in lubrication. It is generally assumed that a greater quantity of oil is required for lubricating valves and cylinders where superheated steam is used, but experience seems to show just the reverse, although positive statements to this effect cannot as yet be made.

6 The statement made by one of the discussers that with 60 deg. superheat at the throttle of an engine 18 deg. were still recorded in the exhaust steam with a vacuum of 24 in., cannot be correct. Take for instance a 20 in. by 30 in. simple engine, working with a 30 per cent cut-off and a steam pressure of 160 lb., it will be necessary to superheat the steam 165 deg. in order to have the exhaust steam 212 deg.

7 In regard to increase of boiler pressure, attention is called to the fact that we are aiming to decrease same, especially in railroad practice. Of course, in that case, it will be necessary to increase the size of the cylinder.

8 In answer to Mr. Seymour's remark in regard to decreasing the efficiency and reliability of a plant as a whole, there is no difficulty in operating properly designed engines with superheated steam, because engines can be simplified for this purpose. In other words, a simple engine using superheated steam will have a higher economy than a compound engine using saturated steam and a compound engine using superheated steam will give better economy than a triple expansion engine working with saturated steam. The heat consumption drops rapidly with superheating up to the point where the superheat is sufficient to produce saturation at the end of expansion, and it still decreases when superheating is carried still higher. It therefore should not be concluded, as in the example given by Mr. Seymour, that the economy with highly superheated steam is but little greater than with moderately superheated steam. If in the example given the speaker had mentioned the different details as to steam pressure, cut-off, type of engine, etc., the writer could probably have replied to this point more intelligently.

9 The lubrication of the cylinder for highly superheated steam is an easy matter when it is properly designed and the piston supported at both ends of the cylinder by liberal bearings.

10 The writer did not intend to convey the idea that the poppet valve is the only proper valve for engines using superheated steam but it is better adapted for that purpose than the Corliss valve because the latter has larger wearing surfaces and cannot therefore be satisfactorily lubricated, especially when steam is used having a temperature of over 500 deg. fahr. Attention is called to the fact that with four piston valves for regulating the steam distribution, very good results have been obtained.

11 The writer perfectly agrees with Mr. Seymour that a just comparison of the efficiency of engines can be drawn only from the heat consumption per horse power hour, but in the final reckoning the economy of any steam plant must be figured at the coal pile. The writer has endeavored to show this in the three tables submitted, but at the same time he calls attention again to diagram 1, in which the British thermal units per horse power hour for steam of different temperatures are given. The following example will give an idea of the economy secured with superheated steam. A pound of saturated steam having a pressure of 100 lb. absolute, contains 1181.2 B.t.u. and has a cubical content of 4.34 cu. ft., which means that each cubic foot of this steam consists of 272.35 B.t.u. If this steam is to be superheated 200 deg. fahr., 96.1 B.t.u. have to be added, which increases the total British thermal units of this pound of steam to

1278.2, while the volume has been enlarged to 5.5 cu. ft. Therefore, each cubic foot of this steam contains now only 235.55 B.t.u. or 13½ per cent less than the cubic foot of saturated steam of the same pressure. The heat added amounted to 8.13 per cent, but the increase in volume is practically 26 per cent. In a 20 in. by 26 in. slide valve engine the port has a cubical content of 660 cu. in., or 0.4 cu. ft. At a cut-off of 30 per cent the superheated steam will give a saving of 7 per cent in clearance alone, which is due to the increase of the volume.

12 In regard to the difficulties of superheating and the troubles and tribulations in using superheated steam, the writer has had opportunities to investigate many cases and he will endeavor to point them out and show the remedies which can be applied. For instance, mention was made of a big power plant equipped with separately fired superheaters. Tests made by Professor Hrabak show plainly that the economy with such superheaters is not very high. A separately fired superheater in which the gases go to waste has no place in any power plant except where it can be fed with waste gases, such as are plentiful in steel or iron works. By proper attention such a superheater can maintain a fairly uniform temperature in the steam and this is probably the reason why this type seems to be in favor in this country.

13 Where the superheater is located in the gas passages and is part of the boiler, the economy in steam and especially in coal will be marked, if the proper degree of superheat is secured and uniformly maintained. These two factors, the proper degree of superheat and the uniformity of the same throughout the different loads a boiler is subjected to, are very important.

14 It is generally conceded that a Corliss valve engine will operate successfully with steam at a temperature of 475 to 500 deg. fahr., but in one instance, which recently came under the observation of the writer, a temperature of 525 deg. fahr. was reached without impairing the working of the different parts of the engine. Under such conditions oil having a high flashing point must be used in a proper way for lubrication.

15 Taking it for granted that a temperature of 500 deg. fahr. is allowable and assuming the steam pressure to be 165 lb. with a temperature of 373 deg. fahr., to be raised 127 deg. by superheating, the per cent gain in steam and coal economy in different types of engines should be as follows at normal load:

TYPE OF ENGINE	SIMPLE NON-CONDENSING		COMPOUND CONDENSING		TRIPLE EXPANSION CONDENSING	
Type of superheater	Separately Fired Per cent	Attached to Boiler Per cent	Separately Fired Per cent	Attached to Boiler Per cent	Separately Fired Per cent	Attached to Boiler Per cent
Saving in steam.....	21	21	15	15	10.5	10.5
Saving in coal.......	8.5	16	1.5	10	−3	6.5

16 But there is not a single power plant in this country which shows such results, although in Europe they are obtained in every day practice. What is the reason for not deriving the same benefit here as in Europe? First of all, European engines are designed for high superheat and can stand the stresses of expansion and contraction due to great fluctuations. Second, the degree of superheat is controlled or regulated according to conditions. Taking, for instance, the above case, the heating surface of the superheater to give 127 deg. fahr. superheat is proportioned for normal load, but any increase of load will naturally increase the degree of superheat, so that with an overload of 50 per cent the superheat will be about 25 deg. higher and with 100 per cent overload about 60 deg. higher. Trouble ensues in consequence and in all cases the superheater heating surface is cut down so as to give at maximum load the degree of superheat wanted, while at normal load the superheat is about high enough to give dry steam.

17 Another factor of irregular and variable superheat is to be found in the elements of the superheater which in most cases consist of round pipes in which only the steam nearest to the wall is superheated, while the core is hardly heated on account of the outer ring of superheated steam acting as a non-conductor. In some superheaters devices are arranged to break up this segregation and mix the steam of different temperatures thoroughly, but generally this is not done. In consequence, the steam reaches the engine in alternate gusts of different degrees of heat and plays havoc with valves, pistons and cylinders, which, of course, discredits at once the advantages of superheated steam. The elements of a superheater should be so constructed that the steam flows through them in a sheet in which form a uniform superheat can be obtained.

18 Another failure in a superheater is the depositing of cinders, soot and ashes on the outside of the elements, which cuts down the efficiency. In many cases flooded superheaters are used, but if anybody wishes to increase his troubles, he needs only to employ this type. Another source of trouble lies in the connection between head-

ers and elements being exposed to the hot gases, which generally ends in leakage. It is, therefore, recommended that the headers and their connections with the elements be located outside of the boiler, which guards against such leakage.

19 The control or regulation of superheat has been accomplished in different ways, but there are only a few which have merits.

a Injecting cold water into the superheater elements. This is not recommended because in time the superheater pipes will be filled up with the incrusting elements of the water.

b By-passing the flue gases or choking the flue passages by dampers. Not rational, because in the latter case the flue area is restricted when it should be largest.

c Admitting cold air onto superheater elements. This is wasteful.

d Superheaters reinforced by great masses of cast iron to store up heat. Costly and also ineffective to a certain degree.

e Hot water circulation through pipes located inside of superheater elements. Too complicated.

f Mixing superheated steam with saturated steam automatically in a comingler.

g Returning excess heat of superheated steam into boiler, thereby not alone increasing evaporating capacity, but improving water circulation.

These last two systems are rational and economical and can be automatically arranged.

20 Last but not least, the degree of superheat to be used is very important. Superheating of steam, although not new, is a peculiar feature in steam engineering and it is not as yet fully understood by all. There are many factors that must be taken into consideration before it can be determined what is the most economical amount of superheat in a given case. What should be the design of engines or turbines for new or old plants and what can be done to improve present conditions as they are found? What are the probable losses in pipe lines? What is the proper type of superheater for a particular plant and what should be its location? Many recent installations have been failures because such points as these have not received attention. These are all engineering problems that should not be left to the manufacturers of engines and boilers, or of other steam appliances, but should be worked out by an expert who is advanced in the art. I venture to say that in the best modern and most economical

high duty power plant in this country, using saturated steam, the economy can be raised from 8 to 10 per cent by a judicious application of superheated steam and that the superheating apparatus will not give any more trouble in such a plant than a first-class boiler.

21 The turbine builders have made the statement that with superheated steam there is economy in steam consumption in turbines, but that no economy in coal consumption has been recorded, and for that reason they recommend only a moderate superheat of about 100 deg. fahr. This is entirely misleading and should be corrected. The tests quoted were on a plant having a separately-fired superheater, the construction of which was of the crudest form, and the fuel arrangment a very wasteful one.

22 In a paper read before the American Street and Inter-urban Railway Association, Mr. A. H. Kruesi gave the results of tests at Chicago with a Curtis turbine coupled to a 9000 kw. generator. The lowest superheated steam consumption of the turbine when developing 13 650 h.p. is given at 9.62 lb. of steam per horse power hour, which probably is the lowest steam consumption of any in this country.

23 Comparing this with results obtained with a 3000 kw. Curtis turbine, built by the *Allegemeine Electricitaets Gesellschaft* of Berlin, at an output of 2554 kw., the steam consumption per horse power hour was 8.3 lb. and at an output of 3169 kw., 8.47 lb. per horse power hour. The turbine ran at 1500 r.p.m., the boiler pressure was 170 lb. and the superheat maintained 220 deg. fahr. This turbine was built especially for highly superheated steam and special care was taken to provide for expansion and contraction of the different parts, and, as the writer understands it, the openings as well as the angles of the different sets of blades were somewhat differently designed to give the steam the proper expansion due to superheat.

24 The writer has tried to explain the features of superheating and their difficulties as thoroughly as his knowledge enables him to do and he can say that in the present state of the art, it is not a question of whether we shall superheat or not, but whether low or high superheat shall be applied. With low superheat very few changes in engine design are necessary, but with high superheat more attention will have to be paid to rational details as outlined in the writer's paper resulting in a high degree of economy, an aim which is worth our while.

No. 1180

POWER TRANSMISSION BY FRICTION DRIVING

BY PROF. W. F. M. GOSS, URBANA, ILL.
Member of the Society

A description of the application of friction wheels to ordinary forms of shaft driving, and an account of experiments made to determine the power capacity of such wheels when made of compressed straw fiber, was presented to the Society in December, 1896, under the caption of "Paper Friction Wheels." The facts herewith given are to be accepted as an extension of the earlier study.

A FRICTION DRIVE

2 A friction drive, as the term is here employed, consists of a fibrous or somewhat yielding driving wheel working in rolling contact with a metallic driven wheel. Such a drive may consist of a pair of plain cylindered wheels mounted upon parallel shafts, or of a pair of beveled wheels, or of any other arrangement which will serve in the transmission of motion by rolling contact. The use of such drives has steadily increased in recent years, with the result that the so called paper wheels have been improved in quality and a considerable number of new materials have been proposed for use in the construction of fibrous wheels.

THE WHEELS TESTED

3 Choosing materials which have been used for such purposes, driving wheels of each of the following materials have been tested:

Straw fiber,
Straw fiber with belt dressing,
Leather fiber,
Leather,
Leather-faced iron,
Sulphite fiber,
Tarred fiber.

Presented at the New York Meeting (December 1907) of The American Society of Mechanical Engineers and forming part of Volume 29 of the Transactions.

4 The straw fiber wheels are worked out of blocks which are built up usually of square sheets of straw board laid one upon another with a suitable cementing material between them and compacted under heavy hydraulic pressure. In the finished wheel, the sheets appear as discs, the edges of which form the face of the wheel. The material works well under a tool, but is harder and heavier than most woods and takes a good superficial polish. The wheel tested was taken from stock.

5 The wheel of straw fiber with belt dressing was similar to that of straw fiber, except that the individual sheets of straw board from which it was made had been treated, prior to their being converted into a block, with a "belt dressing," the composition of which is unknown to the writer.

6 The leather fiber wheel was made up of cemented layers of board, as were those already described, but in this case, the board, instead of being of straw fiber, was composed of ground sole leather cuttings, imported flax and a small percentage of wood pulp. The material is very dense and heavy.

7 The leather wheel was composed of layers or disks of sole leather.

8 The leather-faced iron wheel consisted of an iron wheel having a leather strip cemented to its face. After less than 300 revolutions, the bond holding the leather face failed and the leather separated itself from the metal of the wheel. This wheel proved entirely incapable of transmitting power and no tests of it are recorded.

9 The wheel of sulphite fiber was made up of sheets of board composed of wood pulp. The sulphite board is said to have been made on a steam-drying continuous-process machine in the same way as is the straw board.

10 The tarred fiber wheel was made up of board composed principally of tarred rope stock, imported French flax and a small percentage of ground sole leather cuttings.

11 Each of the fibrous driving wheels was tested in combination with driven wheels of the following materials:

Iron,
Aluminum,
Type metal.

All wheels tested, both driving and driven, were 16 inches in diameter. The face of all driving wheels was $1\frac{3}{4}$ inch, while that of all driven wheels was $\frac{1}{2}$ inch.

12 The purpose of the experiments was to secure information which would permit rules to be formulated defining the power which

may be transmitted by the various combinations of fibrous and metallic wheels already described. To accomplish this, it was necessary to determine for each combination of driving and driven wheel, the coefficient of friction under various conditions of operation; also the maximum pressures of contact which can be withstood by each of the fibrous wheels.

13 The testing machine used is shown diagrammatically by Fig. 1. The principles involved will be made clear by assigning the functions of the actual machine to the several parts of this figure. The shaft *A* runs in fixed bearings, and carries the fibrous friction wheel. This wheel is the driver. Its shaft *A* carries, beside the friction wheel, two belt pulleys, one on either side, belts to which from any conven-

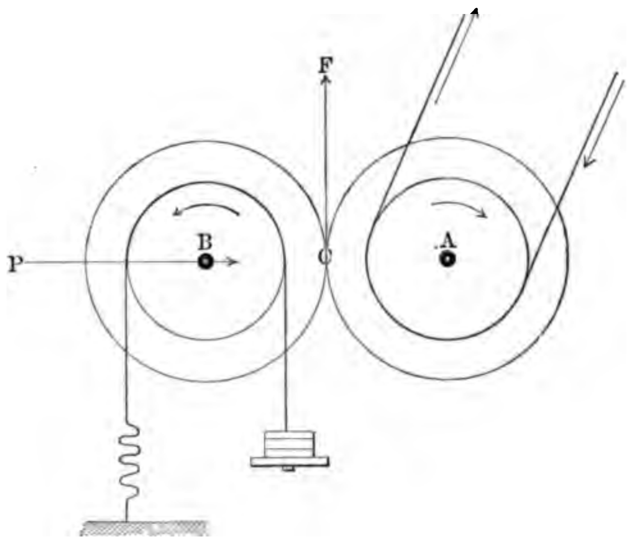

FIG. 1
A DIAGRAMMATIC OUTLINE OF THE TESTING MACHINE

ient source of power, serve to give motion to the driver. The shaft *B* carries the driven wheel which in every case was of metal. The bearings of this shaft are capable of receiving motion in a horizontal direction and by means of suitable mechanism connected therewith, the metal driven wheel may be made to press against the fibrous driver with any force desired. The pressure transmitted from *B* to *A* is hereinafter referred to as the "pressure of contact," and is frequently represented by the symbol *P*. The tangential forces which are transmitted from the driver to the driven wheel are received, absorbed and measured by a friction brake upon the shaft *B*. In action, therefore, the driven wheel always works against a resistance, which resistance may be modified to any desired degree by varying the load upon the brake. The theory of the machine assumes that the energy absorbed by the brake equals that transmitted from the driver to the driven wheel at the contact point C. Accepting this assumption, the forces developed at the periphery of the brake wheel may readily be reduced to equivalent forces acting at the circumference of the driven wheel. This force, which is directly transmitted from the driver to the driven wheel, is hereinafter designated by the symbol F. It will be apparent from this description that the functions of the apparatus employed are such as will permit a study of the relationship existing between the contact pressure P and the resulting transmitted force F, which relation is most conveniently expressed as the coefficient of friction. It is,

$$f = \frac{F}{P}$$

In comparing the work of two friction wheels it is obvious, that the one which develops the highest coefficient of friction, other things being equal, can be depended upon to transmit the greatest amount of power.

14 The actual machine as used in the experiments is shown by Fig. 2. Its construction satisfies all conditions which have been defined except that shaft B, Fig. 1, does not run in bearings which are absolutely frictionless, as is required by a rigid adherence to the theoretical analysis already given. These bearings, however, are of the "standard roller bearing" type, of ample size, and it is believed that the friction actually developed by them is so small compared with the energy transmitted between the wheels that it may be neglected.

15 The bearings of the fixed shaft A are secured to the frame of the machine. The bearings of the axle B are free to move horizontally in guides to which they are well fitted. These bearings are connected by links to the short arm of a bell-crank lever, the longer arm of which projects beyond the frame of the machine at the right hand end and carries the scale-pan and weights E. The effect of the weights is to bring the driven wheel in contact with the driver under a predetermined pressure, the proportions of the bell-crank lever being such as to make this pressure in pounds equal,

$$P = 10\, W + 73$$

where W is the weight on the scale-pan E.

16 The fulcrum of the bell-crank lever is supported by a block *G* which may be adjusted horizontally by the hand wheel *H* at the rear of the machine, so that whatever may be the diameter of the driven wheel, the long arm of the bell-crank may be brought to a horizontal position. The constants employed in calculating the coefficient of friction from observed data are as follows:

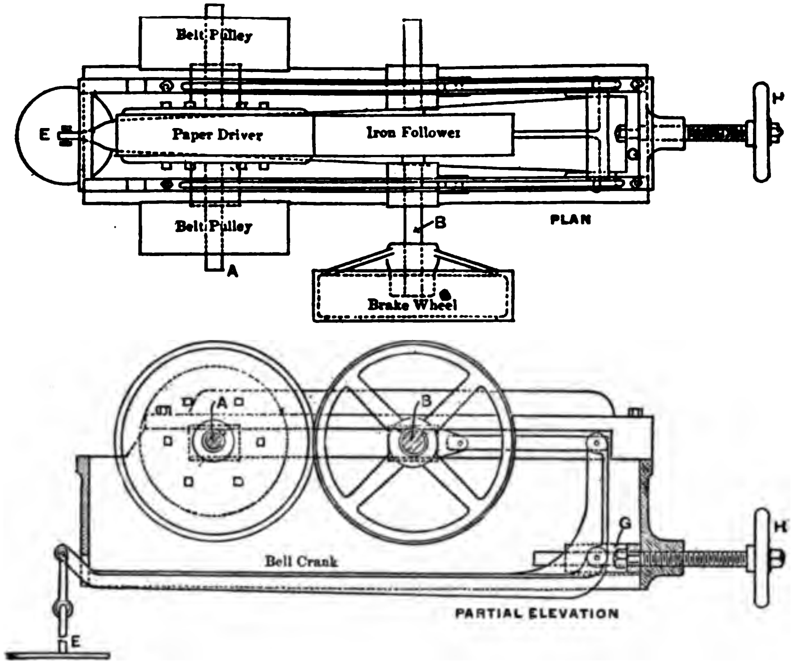

FIG. 2
PLAN AND SECTION OF THE TESTING MACHINE

Diameter of friction wheels (inches)	16
Effective diameter of brake (inches)	18.35
Ratio of diameter of friction wheel to that of brake wheel	1.145
Effective load on brake	F′
Coefficient of friction	$1.145 \frac{F'}{P}$

The slippage between the friction wheels was determined from readings taken from the counters connected to each one of the shafts.

THE TESTS

17 In anticipation of a test, load was applied to the scale-pan *E*, Fig. 2, to give the desired pressure of contact, after which the hand-

[a] Reproduced from Vol. 18, Transactions.

wheel H, at the back of the machine was employed to bring the bell-crank to its normal position. This accomplished, with the driving wheel in motion, the driven wheel would roll with it under the desired pressure of contact, a light load was placed upon the brake to introduce some resistance to the motion of the driven shaft, and the effect of such load in producing slippage between the driver and driven wheel was from time to time noted. When the rate of slippage had become constant, time was noted and readings of the counters taken as the initial data of a test. After an interval varying from one hour to two and a half hours, depending upon the rate of slip, the counters were again read, time again noted, and the test assumed to have ended. From the readings of the counters, and from the known diameters of the wheels in contact, the per cent of slip attending the action of the friction wheels was calculated. Three facts were thus made of record, namely: the pressure of contact, the coefficient of friction developed, and the per cent of slip resulting from the development of said coefficient of friction.

18 This record having been completed, the load upon the brake was increased, and observations repeated, giving for the same pressure of contact, a new coefficient of friction and a higher percentage of slip. This process was continued until the slippage became excessive and until in consequence thereof, the rotation of the driver ceased. By this process a series of tests was developed disclosing the relation between slip and coefficient of friction for the pressure in question. Such a series having been completed, the load upon the weight holder E was changed, giving a new pressure of contact, and the whole process repeated. As the work proceeded, curves showing the relation of coefficient of friction and slip for pressures per inch width of face in contact, of 150 pounds and 400 pounds, respectively, were secured. The curves shown by Fig. 3 and Fig. 4 for the straw fiber driving wheel, in contact with the iron driven wheel are typical in their general form of those obtained from all combinations of wheels.

19 Having completed this series of tests at constant pressure, a series was next run for which the coefficient of slip was maintained constant at 2 per cent and the pressure of contact varied from values which were low to those which were judged to be near the maximum for service conditions, with results which in all cases were similar in character with those given for the straw fiber and iron wheels, as set forth by Fig. 5. The numerical values of the points for other combinations were not the same as those shown by Fig. 5, but in the case of most of the combinations the coefficient of friction at constant slip gradually diminishes as the pressure of contact is increased. With

this understanding of the general character of the results, the precise facts in each case are presented in numerical form rather than graphically. See Appendix. Table 1-8.

20 As the series of tests involving each combination of wheels proceeded, the increase in pressure of contact was discontinued when the markings made upon the driving wheel by the metallic follower became so distinct as to suggest that a safe limit had been reached,

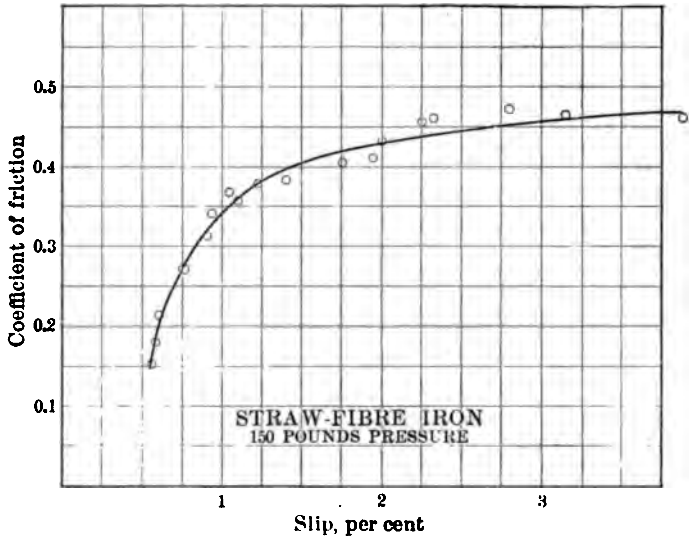

FIG. 3

COEFFICIENT OF FRICTION AND SLIP UNDER 150 LBS. PRESSURE

but later when all other data had been secured, tests were run for the purpose of determining the ultimate resistance of the fibrous wheel to crushing. The details of these will be described later.

Coefficient of Friction Developed by the Several Combinations of Wheels

STRAW FIBER AND IRON

21 The results of experiments involving a straw fiber driver, and an iron driven wheel are presented in the Appendix as Tests 1 to 36, Table 1. They are shown graphically in Fig. 3, 4 and 5. Fig. 4 and 5 illustrate the relation between slip and coefficient of friction when the two wheels are working together under pressures per inch width of 150 and 400 pounds, respectively.

22 The figures show that although the values of the coefficient of friction for 400 pounds pressure are slightly lower than corresponding

ones for 150 pounds pressures, the curves are sufficiently similar to establish the fact that the law governing change in coefficient of

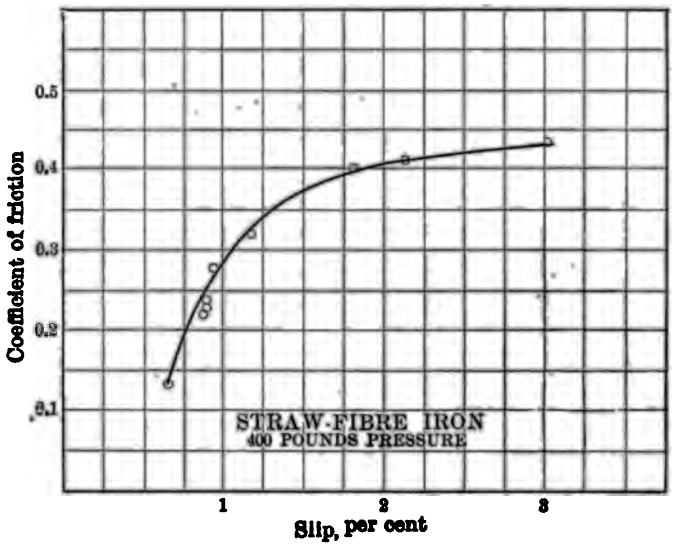

FIG. 4
COEFFICIENT OF FRICTION AND SLIP UNDER 400 LBS. PRESSURE

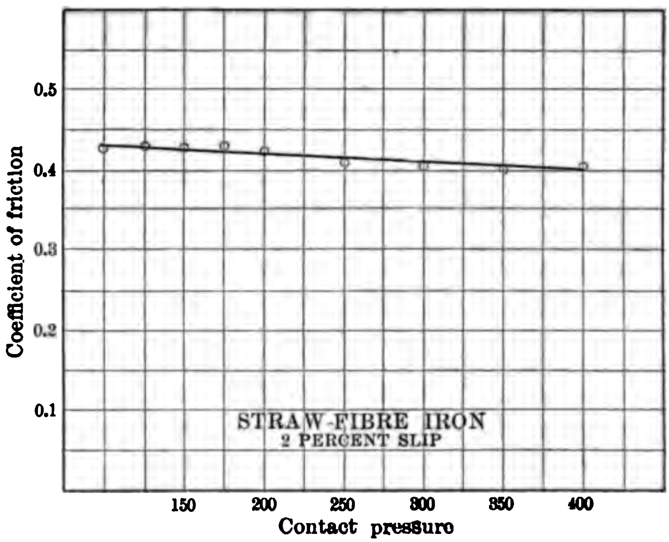

FIG. 5
COEFFICIENT OF FRICTION UNDER DIFFERENT PRESSURES, SLIP CONSTANT

friction with slip is independent of the pressure of contact. When the slippage is 2 per cent, the coefficient of friction is 0.425 for a contact pressure of 150 pounds, and 0.410 for a contact pressure of 400 pounds. That the coefficients of friction for all pressures between the limits of 150 pounds and 400 pounds are practically constant is well shown by the diagram Fig. 5. The pressure of 400 pounds is the maximum at which tests of this combination of wheels were run, though straw fiber was successfully worked up to a pressure of 750 pounds.

STRAW FIBER AND ALUMINUM

23 The results of experiments involving a straw fiber driver and an aluminum driven wheel are given in the Appendix as Tests 37 to 60, Table 1. By curves plotted from values given, it can be shown that when the working pressure is 150 pounds per inch width and the slippage is 2 per cent, the coefficient of friction is 0.455; also, that for all pressures ranging from 100 to 400 pounds, the coefficient of friction is practically constant when the rate of slip is constant. The maximum pressure at which tests involving this combination of wheels were run was 400 pounds per inch width.

STRAW FIBER AND TYPE METAL

24 The results of experiments involving a straw fiber driver and a type metal driven wheel are presented in the Appendix as Tests 61 to 87, Table 1. By curves plotted from values given, it can be shown that when the two wheels are operated under a pressure of contact of 150 pounds per inch width and when the slip is 2 per cent, the coefficient of friction is 0.310; also, that for all pressures of contact ranging from 100 to 400 pounds, the coefficient of friction is practically constant when the slip is constant.

STRAW FIBER WITH BELT DRESSING AND IRON

25 The results of the experiments involving a straw fiber driver treated with belt dressing, and an iron driven wheel are presented in the Appendix as Tests 88 to 103, Table 2. Curves plotted from values given show that when the two wheels are worked together under a pressure of 150 pounds per inch width and when the slip is 2 per cent, the coefficient of friction is 0.12; also, that for all pressures up to 400 pounds per inch width, the coefficient of friction remains constant. The greatest pressure at which tests of this combination of wheels were run was 500 pounds per inch width.

LEATHER FIBER AND IRON

26 The results of tests involving a leather fiber driver and an iron driven wheel are presented in the Appendix as Tests 104 to 127, Table 3. Curves plotted from these results show that when the two wheels are worked together under pressures of 150 pounds per inch in width and when the slip is 2 per cent, the coefficient of friction is 0.515. When the contact pressure is 300 pounds per inch width, the coefficient of friction is 0.510. The greatest pressure at which tests of this combination of wheels were run was 350 pounds per inch width, although leather fiber was successfully worked up to a pressure of 1200 pounds per inch width.

LEATHER FIBER AND ALUMINUM

27 The results of experiments involving a leather fiber driver and an aluminum driven wheel are presented in the Appendix as Tests 128 to 134, Table 3. Curves plotted from these results show that under a contact pressure of 150 pounds per inch width and a slip of 2 per cent, the coefficient of friction is 0.495. This value remains practically constant under all pressures. The maximum pressure used in tests of this combination of wheels was 400 pounds.

LEATHER FIBER AND TYPE METAL

28 The results of experiments involving a leather fiber driver and a type metal driven wheel are presented in the Appendix as Tests 135 to 146, Table 3. Curves plotted from these results show that when the wheels are operated under a contact pressure of 150 pounds per inch width and when the slip is 2 per cent, the coefficient of friction is 0.305; also, that with the slip constant, the coefficient of friction remains constant for all pressures up to 400 pounds per inch width.

TARRED FIBER AND IRON

29 The results of the experiments involving a tarred fiber driver and an iron driven wheel are presented in the Appendix as Tests 147 to 166 and 267 to 269, Table 4. Curves plotted from these results show that the change in the value of the coefficient of friction with change of slip is practically independent of the pressure of contact. When the slip is 2 per cent, the coefficient of friction is 0.220 for a pressure of contact of 150 pounds, and 0.250 for a pressure of contact of 400 pounds per inch width.

FOLDER 1

30 The fact that the data for this combination appear in two series results from the use of a duplicate tarred fiber driver. Tests of this combination were made also under different speeds when the wheels were working together under a pressure of contact of 250 pounds per inch width and when the slip was 2 per cent, with the result that the coefficient of friction was found to remain nearly constant for peripheral speeds of 450 and 3350 feet per minute, respectively. The greatest pressure at which tests of this combination of wheels were run was 400 pounds per inch width, although tarred fiber was successfully worked up to a pressure of 1200 pounds per inch width.

TARRED FIBER AND ALUMINUM

31 The results of experiments involving a tarred fiber driver and an aluminum driven wheel are presented in the Appendix as Tests 167 to 186, Table 4. Curves plotted from these results show that when the slip was 2 per cent and the pressure of contact 150 pounds per inch width, the coefficient of friction is 0.305; also, that for a pressure of 400 pounds per inch width, the coefficient of friction is 0.295. The greatest pressure at which tests of this combination were run was 400 pounds per inch width.

TARRED FIBER AND TYPE METAL

32 The results of experiments involving a tarred fiber driver and a type metal driven wheel are presented in the Appendix as Tests 187 to 202, Table 4. Curves plotted from these results show that when the slip is 2 per cent, the coefficient of friction developed under 150 pounds pressure per inch width is 0.275; and under 400 pounds pressure per inch width, the coefficient of friction is 0.270. The maximum pressure at which tests of this combination of wheels were run was 400 pounds per inch width.

LEATHER AND IRON

33 The results of experiments involving a leather driver and an iron driven wheel are presented in the Appendix as Tests 203 to 220, Table 5. Curves plotted from these results show that when the slip is 2 per cent, the coefficient of friction under a pressure of contact of 150 pounds per inch in width, is 0.225, and under a pressure of 400 pounds, 0.215. The maximum pressure at which tests of this combination of wheels were run was 400 pounds per inch width, although the leather driver was successfully operated up to a pressure of 750 pounds per inch width.

LEATHER AND ALUMINUM

34 The results of experiments involving a leather driver and an aluminum driven wheel are presented in the Appendix as Tests 221 to 234, Table 5. Curves plotted from these results show that when the pressure is 150 pounds per inch in width, and the slip is 2 per cent, the coefficient of friction is 0.260, and when the pressure is 300 pounds per inch in width, the coefficient of friction is 0.295. The maximum pressure at which tests of this combination of wheels were made was 350 pounds per inch width.

LEATHER AND TYPE METAL

35 The results of the experiments involving a leather driver and a type metal driven wheel are presented in the Appendix as Tests 235 to 239, Table 5. Curves plotted from these results show that when the slip is 2 per cent and the contact pressure 150 pounds per inch width, the coefficient of friction developed is 0.410. The greatest pressure at which tests of this combination of wheels were run was 350 pounds per inch width.

SULPHITE FIBER AND IRON

36 The results of the experiments involving a sulphite fiber driver and an iron driven wheel are presented in the Appendix as Tests 240 to 245, Table 5. Curves plotted from these results show that when the slip is 2 per cent and the pressure 150 pounds per inch width, the coefficient of friction is 0.550. The maximum pressure at which tests of this combination of wheels were run was 350 pounds per inch width, although the sulphite fiber wheel was successfully operated up to a pressure of 700 pounds per inch width.

SULPHITE FIBER AND ALUMINUM

37 The results of the experiments involving a sulphite fiber driver and an aluminum wheel are presented in the Appendix as Tests 245 to 249, Table 5. Curves plotted from these values show that when the slip is 2 per cent and the pressure 150 pounds per inch width, the coefficient of friction developed is 0.410. The greatest pressure used in tests of this combination of wheels was 350 pounds per inch width.

SULPHITE FIBER AND TYPE METAL

38 The results of the experiments involving a sulphite fiber driver and a type metal driven wheel are presented in the Appendix as

Tests 250 to 254, Table 6. Curves plotted from these results show that when the slip is 2 per cent and the contact pressure 150 pounds per inch width, the coefficient of friction is 0.515. The maximum pressure used in tests of this combination of wheels was 350 pounds per inch width.

RESISTANCE TO CRUSHING

39 Upon the completion of tests designed to disclose the frictional qualities of the several combinations, each fibrous wheel was subjected to a test designed to disclose the maximum pressure per inch width of the face which could be sustained by it. This was accomplished by placing the wheel to be tested in the machine, under a pressure of contact of 200 pounds per inch width. The load on the brake was then adjusted to give a 2 per cent slip. Thus adjusted, the machine was operated until the driver had completed 15 000 revolutions, after which and for the purpose of determining the reduction, if any, in the diameter of the fibrous wheel, the brake load was removed and the operation of the machine continued without load for a period of 6000 revolutions, the readings of the counters being taken at the beginning and end of the period. With no load, the actual slip was assumed to be zero and the apparent slip observed was used for determining the reduction in diameter of the fibrous wheel which had been brought about by the previous running under pressure. This accomplished, the pressure of contact was increased, usually by 100-pound increments, and the whole operation repeated. This process was continued until failure of the fibrous wheel resulted. It will be seen that the ultimate resistance to crushing, as found by the process described, is that pressure which could not be endured during 15 000 revolutions.

40 A summary of results is as follows:

STRAW FIBER

Load	Decrease in diam.	Load	Decrease in diam.	Load	Decrease in diam.
200	0.000	650	0.053	750	0.125

Note—The wheel failed before running 15 000 revolutions under 750 pounds pressure.

LEATHER FIBER

Load	Decrease in diam.	Load	Decrease in diam.	Load	Decrease in diam.
200	0.000	600	0.027	1000	0.099
300	0.005	700	0.040	1100	0.125
400	0.013	800	0.051	1200	0.200
500	0.021	900	0.068		

Note—The wheel failed before running 15 000 revolutions under 1200 pounds pressure.

TARRED FIBER

Load	Decrease in diam.	Load	Decrease in diam.	Load	Decrease in diam.
200	0.000	600	0.071	1000	0.250
300	0.026	700	0.098	1100	0.295
400	0.038	800	0.138	1200	
500	0.052	900	0.182		

Note—The wheel failed before running 15 000 revolutions under 1200 pounds pressure.

LEATHER

Load	Decrease in diam.	Load	Decrease in diam.	Load	Decrease in diam.
350	0.047	550	0.150	750	
450	0.090	650	0.240		

Note—The wheel failed before running 15 000 revolutions under 750 pounds pressure.

SULPHITE FIBER

Load	Decrease in diam.	Load	Decrease in diam.	Load	Decrease in diam.
200	0.010	400	0.056	600	0.146
300	0.032	500	0.088	700	0.258

Note—The wheel failed before running 15 000 revolutions under 700 pounds pressure.

A CONCLUSION AS TO METAL WHEELS

41 An examination of Table 9, which presents a comparison of values representing the coefficient of friction of the several combinations of wheels tested, reveals the fact that the relative value of the metal driven wheels is not the same when operated in combination with different fibrous driving wheels. It appears that those driving wheels which are the more dense, work more efficiently with the iron follower than with either the aluminum or type metal followers but in the case of the softer and less dense driving wheels, and especially in the case of those in which an oily substance is incorporated, driven wheels of aluminum and type metal are superior to those of iron. Finely powdered metal which is given off from the surface of the softer metal wheels seems to account for this effect and the character of the driving wheels is perhaps the only factor necessary to determine whether its presence will be beneficial or detrimental. Finally, with reference to the use of soft metal driven wheels, it should be noted that no combination of such wheels with a fibrous driver appears to have given high frictional results. Except when used under very light pressures, the wear of the type metal was too rapid to make a wheel of this material serviceable in practice.

CONCLUSIONS AS TO FIBROUS WHEELS

42 The relative value of the different fibrous wheels when employed as drivers in a friction drive may be judged by comparing their

frictional qualities as set forth in Table 9 and their strength as set forth in paragraph 41. The results show at once that the addition of belt dressing to the composition of a straw fiber wheel is fatal to its frictional qualities. The highest frictional qualities are possessed by the sulphite fiber wheel which, on the other hand, is the weakest of all wheels tested. The leather fiber and tarred fiber are exceptionally strong and the former possesses frictional qualities of a superior order. The plain straw fiber which in a commercial sense is the most available of all materials dealt with, when worked upon an iron follower, possesses frictional qualities which are far superior to leather, and strength which is second only to the leather fiber and the tarred fiber.

The Power Capacity of Friction Gears

CONCERNING THE APPLICATION OF RESULTS

43 A review of the data discloses the fact that several of the friction wheels tested developed a coefficient of friction which in some cases exceeded 0.5. That is, such wheels rolling in contact have transmitted from driver to driven wheels a tangential force equal to 50 per cent of the force maintaining their contact. These wheels, also, were successfully worked under pressures of contact approaching 500 pounds per inch in width. Employing these facts as a basis from which to calculate power, it can readily be shown that a friction wheel a foot in diameter, if run at 1000 revolutions per minute, can be made to deliver in excess of 25 horse power for each inch in width. It is certainly true that any of the wheels tested may be employed to transmit for a limited time an amount of power which, when gaged by ordinary measures, seems to be enormously high, but obviously, performance under limiting conditions should not be made the basis from which to determine the commercial capacity of such devices. In view of this fact, it is important that there be drawn from the data such general conclusions with reference to pressures of contact, and frictional qualities as will constitute a safe guide to practice.

WORKING PRESSURE OF CONTACT

44 The results of these experiments do not furnish an absolute measure of the most satisfactory pressure of contact for service conditions. Other things being equal, the power transmitted will be proportional to this pressure and hence it is desirable that the value be made as high as practicable. On the other hand, it has been noted as one of the observations of the test that as higher pressures are used,

there appears to be a gradual yielding of the structure of the fibrous wheels, and it is reasonable to conclude that the life of a given wheel will in a large measure depend upon the pressure under which it is required to work. After a careful study of the facts involved, it has been determined to base an estimate of the power which may be transmitted upon a pressure of contact which is 20 per cent of the ultimate resistance of the material as established by the crushing tests already described. This basis gives the following results:

SAFE WORKING PRESSURES OF CONTACT

	Pressure
Straw fiber	150
Leather fiber	240
Tarred fiber	240
Sulphite fiber	140
Leather	150

COEFFICIENT OF FRICTION

45 The coefficient of friction for all wheels tested approaches its maximum value when the slip between driver and driven wheel amounts to 2 per cent and, within narrow limits, its value is practically independent of the pressure of contact. A summary of maximum results is shown by Table 9. In view of the facts presented, it is proposed to base a measure of the power which may be transmitted by such friction wheels as those tested upon the frictional qualities developed at a pressure of 150 pounds per inch of width, when operating under a load causing 2 per cent slip. For safe operation, however, deductions must be made from the observed values. Thus, the results of the experiments disclose the power transmitted from wheel to wheel, while in the ordinary application of friction drives some power will be absorbed by the journals of the driven axle so that the amount of power which can be taken from the driven shaft will be somewhat less than that transmitted to the wheel on said shaft. Again, under the conditions of the laboratory, every precaution was taken to keep the surfaces in contact free of all foreign matter. It was, for example, observed that the accumulation of laboratory dust upon the surfaces of the wheels had a temporary effect upon the frictional qualities of the wheels, and friction wheels in service are not likely to be as carefully protected as were those in the laboratory. In view of these facts, it has been thought proper to use as the basis from which to determine the amount of power which may be transmitted by such wheels as those tested, a coefficient of friction which shall be 60 per cent of that developed under the conditions of the laboratory. This basis gives the following results:

COEFFICIENT OF FRICTION—WORKING VALUES

	Coefficient of friction
Straw fiber and iron	0.255
Straw fiber and aluminum	0.273
Straw fiber and type metal	0.186
Leather fiber and iron	0.309
Leather fiber and aluminum	0.297
Leather fiber and type metal	0.183
Tarred fiber and iron	0.150
Tarred fiber and aluminum	0.183
Tarred fiber and type metal	0.165
Sulphite fiber and iron	0.330
Sulphite fiber and aluminum	0.318
Sulphite fiber and type metal	0.309
Leather and iron	0.135
Leather and aluminum	0.216
Leather and type metal	0.246

HORSE POWER

46 Having now determined a safe working pressure of contact and a representative value for the coefficient of friction, it is possible to formulate equations expressing the horse power which may be transmitted by each combination of wheels tested. Thus, calling d the diameter of the friction wheel in inches, W the width of its face in inches and N the number of revolutions per minute, the equations become, for combinations of,

Straw fiber and iron	h.p. = $0.00030\ dWN$
Straw fiber and aluminum	h.p. = $0.00033\ dWN$
Straw fiber and type metal	h.p. = $0.00022\ dWN$
Leather fiber and iron	h.p. = $0.00059\ dWN$
Leather fiber and aluminum	h.p. = $0.00057\ dWN$
Leather fiber and type metal	h.p. = $0.00035\ dWN$
Tarred fiber and iron	h.p. = $0.00029\ dWN$
Tarred fiber and aluminum	h.p. = $0.00035\ dWN$
Tarred fiber and type metal	h.p. = $0.00031\ dWN$
Sulphite fiber and iron	h.p. = $0.00037\ dWN$
Sulphite fiber and aluminum	h.p. = $0.00035\ dWN$
Sulphite fiber and type metal	h.p. = $0.00034\ dWN$
Leather and iron	h.p. = $0.00016\ dWN$
Leather and aluminum	h.p. = $0.00026\ dWN$
Leather and type metal	h.p. = $0.00029\ dWN$

47 By use of the first of these formulae, values have been calculated showing the horse power which may be transmitted by a straw fiber driver of one inch width of face in contact with an iron driven wheel. These values are presented as Table 10 accompanying. They

include diameters which range from 3 to 53 inches and speeds of revolutions ranging from 100 to 2000. While the values of this table apply only to a combination of straw fiber and iron, it is possible by the use of a mutiplier to secure from them values which correspond to other combinations. Such a list of mutipliers is given below:

MULTIPLIERS

Straw fiber and aluminum	= 1.10
Straw fiber and type metal	= 0.73
Leather fiber and iron	= 1.97
Leather fiber and aluminum	= 1.90
Leather fiber and type metal	= 1.17
Tarred fiber and iron	= 0.97
Tarred fiber and aluminum	= 1.17
Tarred fiber and type metal	= 1.03
Sulphite fiber and iron	= 1.23
Sulphite fiber and aluminum	= 1.17
Sulphite fiber and type metal	= 1.13
Leather and iron	= 0.53
Leather and aluminum	= 0.87
Leather and type metal	= 0.97

48 For example, to determine the amount of power which can be transmitted by a given friction wheel of sulphite fiber working upon an iron driven wheel, values which are given in Table 10 should be multiplied by 1.2. Such of these multipliers as are likely to be most used are presented with the table.

49 A more flexible means of approach to the general problem involved by the use of fibrous friction wheels than that given by Table 10 is supplied by Fig. 36. This chart gives a convenient means of determining the value of any one of the variable factors in the formula h. p. $= 0.0003\,dWN$ for the straw fiber friction wheel working in combination with an iron follower, the remaining factors being known or assumed.

a *To find peripheral speed,* locate the intersection of the vertical line representing the given speed in revolutions per minute with the diagonal one representing the given diameter. The horizontal line passing through this point will give the surface speed in feet per minute on the vertical scale to the right of the diagram.

b *To find the horse power for a given wheel,* locate the intersection of the vertical line representing the given speed in revolutions per minute with the diagonal line representing the given diameter. Follow the horizontal line passing through this point to the right or left until the intersection between it and the vertical line representing the given width, as shown on the scale at the top of the diagram, is reached The diagonal line passing through this point marked "Total horse power" will represent the required horse power.

c *To find the face width of a given wheel* necessary to transmit a given horse power, the speed being known, locate the intersection of the vertical line representing the given speed in revolutions per minute with the diagonal line representing the given diameter. Follow the horizontal line passing through this point to the right or left until the intersection between it and the diagonal line representing the required horse power is reached. The vertical line passing through this point will give the width of face in inches on the scale at the top of the diagram.

Application of Results to Face Friction Gearing

50 A fibrous driving wheel, acting upon the face of a metal disk, constitutes a form of friction gear which is serviceable for a variety of purposes. If the driver is so mounted that it may be moved across the face of the disk, the velocity ratio may be varied, and the direction of the disk's motion may be reversed. The contact is not one of pure rolling. If the driver is cylindrical in form, the action along its line of contact with the disk is attended by slip, the amount of which changes for every different point along the line. The recognition of this fact is essential to a discussion of the power transmitting capacity of the device.

51 Experiments involving the spur form of friction wheels already described have shown that slip greatly affects the coefficient of friction; that the coefficient approaches its maximum value when the slip reaches 2 per cent, and that when the slip exceeds 3 per cent, the coefficient diminishes. It is known that reductions in the value of the coefficient with increments of slip beyond 3 per cent are at first gradual, although the characteristics of the testing machine have not permitted a definition of this relation for slip greater than 4 per cent. The experiments, however, fully justify the statement that for maximum results, the slippage should not be less than 2 per cent nor more than 4 per cent. It is the maximum limit with which we are concerned in considering the amount of power which may be transmitted by face friction gearing.

52 From the discussion of the previous paragraph, it should be evident that, for best results, the width of face of the friction driver, and the distance between the driver and center of disk, should always be such that the variations in the velocity of the particles of the disk having contact with the driver will not exceed 4 per cent. A convenient rule which, if followed, will secure this condition, is to make the minimum distance between the driver and the center of the driven disk twelve times the width of the face of the driver. For example, a driver having a $\frac{1}{4}$ inch width of face should be run at a distance of 3 inches or more from the center of the disk. Similarly, drivers having faces $\frac{1}{2}$, 1 or 2 inches in width should be run at a distance from the center of the disc of not less than 6, 12 or 24 inches, respectively. When these conditions are met, all formulae for calculating the power which may be transmitted, also, the values of Table 10, apply directly to the conditions of face driving.

53 It may not infrequently happen that friction wheels must be run nearer the center of the disk than the distance specified, and there is, of course, no objection to such practice, but it should not be forgotten that as the center of the disk is approached, the coefficient of friction, and consequently, the capacity to transmit power, diminishes.

CONDITIONS TO BE OBSERVED IN THE INSTALLATION OF FRICTION DRIVES

54 Whatever may be the form of the transmission, the fibrous wheel must always be the driver. Neglect of this rule is likely to result in failure which will appear in the unequal wear of the softer wheel, occasioned by slippage.

55 The rolling surfaces of the wheel should be kept clean. Ordinarily, they should not be permitted to collect grease or oil, nor be exposed to excessive moisture. Where this can not be prevented, a factor of safety should be provided by making the wheels larger than normal for the power to be transmitted.

56 Since the power transmitted is directly proportional to the pressure of contact, it is a matter of prime importance that the mechanical means employed in maintaining the contact be as nearly as possible inflexible. For example, arrangements of friction wheels which involve the maintenance of contact through the direct action of a spring have been found unsatisfactory, since any defect in the form of either wheel introduces vibrations which tend to impair the value of the arrangement. It is recommended that springs be

avoided and that contact be secured through mechanism which is rigid and which when once adjusted shall be incapable of bringing about any release of the pressure to which it is set.

ACKNOWLEDGMENTS

57 The writer is under obligations to the Rockwood Manufacturing Company of Indianapolis, and especially to Mr. George R. Rockwood of said Company, for supplies of materials and for helpful suggestions, also, to Mr. Paul Diserens, Junior Member of the Society, for assistance rendered in running the tests.

APPENDIX

A Summary of Observed and Calculated Results

TABLE 1 SUMMARY OF DATA STRAW FIBER

No.	Follower	Revolutions per minute	Slip (per cent)	Contact pressure (pounds per inch)	Coefficient of friction
A	B	C	D	E	F
1	Iron	182	0.56	150	0.153
2	Iron	173	0.58	150	0.179
3	Iron	174	0.61	150	0.213
4	Iron	207	0.78	150	0.271
5	Iron	207	0.99	150	0.313
6	Iron	200	1.10	150	0.359
7	Iron	175	1.40	150	0.386
8	Iron	200	1.22	150	0.381
9	Iron	173	1.94	150	0.411
10	Iron	203	2.25	150	0.458
11	Iron	203	2.79	150	0.473
12	Iron	205	2.33	150	0.463
13	Iron	206	3.15	150	0.465
14	Iron	173	1.04	150	0.368
15	Iron	178	1.75	150	0.405
16	Iron	170	2.00	150	0.432
17	Iron	170	3.90	150	0.446
18	Iron	220	2.02	100	0.430
19	Iron	220	2.00	125	0.431
20	Iron	220	2.10	175	0.432
21	Iron	200	1.80	200	0.436
22	Iron	157	1.62	225	0.440
23	Iron	180	2.20	150	0.420
24	Iron	174	2.10	200	0.427
25	Iron	161	2.25	250	0.422
26	Iron	165	2.02	300	0.405
27	Iron	165	2.02	350	0.401
28	Iron	211	2.12	400	0.410
29	Iron	210	0.65	400	0.129
30	Iron	222	0.87	400	0.217
31	Iron	219	0.88	400	0.228
32	Iron	216	0.90	400	0.234
33	Iron	216	0.93	400	0.275
34	Iron	210	1.16	400	0.318
35	Iron	162	1.80	400	0.400
36	Iron	212	3.00	400	0.435
37	Aluminum	190	0.53	150	0.162
38	Aluminum	195	0.57	150	0.212
39	Aluminum	210	0.60	150	0.215
40	Aluminum	190	0.63	150	0.244
41	Aluminum	195	0.78	150	0.290
42	Aluminum	215	1.26	150	0.372
43	Aluminum	212	1.56	150	0.395
44	Aluminum	200	1.79	150	0.421
45	Aluminum	196	1.90	150	0.446
46	Aluminum	197	3.01	150	0.481
47	Aluminum	193	3.26	150	0.499
48	Aluminum	213	2.12	100	0.464
49	Aluminum	212	1.90	100	0.458
50	Aluminum	213	1.86	125	0.453

TABLE 1 SUMMARY OF DATA STRAW FIBER—Continued

No.	Follower	Revolutions per minute	Slip (per cent)	Contact pressure (pounds per inch)	Coefficient of friction
A	B	C	D	E	F
51	Aluminum.........	212	2.27	125	0.462
52	Aluminum.........	212	1.80	175	0.451
53	Aluminum.........	202	1.86	175	0.471
54	Aluminum.........	203	2.02	200	0.468
55	Aluminum.........	214	2.10	200	0.453
56	Aluminum	202	1.80	225	0.445
57	Aluminum	210	2.20	250	0.458
58	Aluminum	210	2.05	300	0.445
59	Aluminum	210	2.15	350	0.437
60	Aluminum	210	1.93	400	0.440
61	Type Metal	214	0.50	150	0.114
62	Type Metal	180	0.58	150	0.164
63	Type Metal	209	0.63	150	0.153
64	Type Metal	223	0.71	150	0.191
65	Type Metal	194	0.73	150	0.199
66	Type Metal	226	0.84	150	0.229
67	Type Metal	187	1.12	150	0.233
68	Type Metal	220	1.18	150	0.244
69	Type Metal	220	1.20	150	0.262
70	Type Metal	188	1.50	150	0.246
71	Type Metal	190	1.54	150	0.252
72	Type Metal	220	1.70	150	0.276
73	Type Metal	187	1.73	150	0.256
74	Type Metal	180	2.01	150	0.290
75	Type Metal	211	2.07	150	0.302
76	Type Metal	180	2.40	150	0.298
77	Type Metal	211	3.48	150	0.317
78	Type Metal	218	3.84	150	0.308
79	Type Metal	209	4.80	150	0.332
80	Type Metal	173	1.70	100	0.327
81	Type Metal	180	1.84	125	0.317
82	Type Metal	208	2.00	150	0.306
83	Type Metal	214	1.90	175	0.295
84	Type Metal	211	2.30	200	0.295
85	Type Metal	209	2.01	225	0.294
86	Type Metal	208	2.10	250	0.288
87	Type Metal	210	2.10	300	0.290

TABLE 2 SUMMARY OF DATA STRAW FIBER BELT DRESSING

No.	Follower	Revolutions per minute	Slip (per cent)	Contact pressure (pounds per inch)	Coefficient of friction
A	B	C	D	E	F
88	Iron..............	225	0.80	150	0.053
89	Iron..............	225	0.88	150	0.061
90	Iron..............	220	1.33	150	0.084
91	Iron..............	225	1.35	150	0.092
92	Iron..............	223	1.60	150	0.107
93	Iron..............	224	2.00	150	0.119
94	Iron..............	223	2.15	150	0.133
95	Iron..............	220	2.16	150	0.111
96	Iron..............	220	3.31	150	0.130
97	Iron..............	182	2.18	200	0.122
98	Iron..............	182	2.30	250	0.124
99	Iron..............	180	2.12	300	0.111
100	Iron..............	180	2.18	350	0.109
101	Iron..............	186	2.20	400	0.103
102	Iron..............	215	2.20	450	0.100
103	Iron..............	220	2.20	500	0.100

TABLE 3 SUMMARY OF DATA LEATHER FIBER

No.	Follower	Revolutions per minute	Slip (per cent)	Contact pressure (pounds per inch)	Coefficient of friction
A	B	C	D	E	F
104	Iron..............	179	0.64	150	0.146
105	Iron..............	175	0.70	150	0.213
106	Iron..............	167	0.75	150	0.262
107	Iron..............	178	0.86	150	0.297
108	Iron..............	180	0.94	150	0.396
109	Iron..............	170	1.30	150	0.411
110	Iron..............	210	1.54	150	0.460
111	Iron..............	208	1.58	150	0.484
112	Iron..............	208	1.74	150	0.505
113	Iron..............	208	1.90	150	0.519
114	Iron..............	190	2.32	150	0.534
115	Iron..............	168	2.45	150	0.512
116	Iron..............	168	2.80	150	0.542
117	Iron..............	191	2.90	150	0.565
118	Iron..............	206	1.98	200	0.526
119	Iron..............	200	2.04	250	0.509
120	Iron..............	200	2.00	300	0.510
121	Iron..............	200	2.05	350	0.496
122	Iron..............	220	0.64	300	0.122
123	Iron..............	200	0.94	300	0.300
124	Iron..............	198	1.05	300	0.374
125	Iron..............	190	1.22	300	0.443
126	Iron..............	211	1.60	300	0.474
127	Iron..............	190	2.85	300	0.530
128	Aluminum.........	211	1.92	400	0.481
129	Aluminum.........	211	2.01	350	0.480
130	Aluminum.........	211	2.10	300	0.485
131	Aluminum.........	211	2.15	250	0.502
132	Aluminum.........	211	2.00	200	0.490
133	Aluminum.........	211	2.00	150	0.490
134	Type Metal........	220	0.75	150	0.163
135	Type Metal........	220	0.97	150	0.222
136	Type Metal........	220	1.05	150	0.222
137	Type Metal........	220	1.30	150	0.254
138	Type Metal........	220	1.78	150	0.298
139	Type Metal........	220	2.20	150	0.320
140	Type Metal........	220	2.75	150	0.336
141	Type Metal........	220	3.80	150	0.336
142	Type Metal........	216	2.05	200	0.304
143	Type Metal........	216	2.08	250	0.311
144	Type Metal........	217	2.10	300	0.313
145	Type Metal........	207	1.90	350	0.314
146	Type Metal........	207	2.00	400	0.310

TABLE 4 SUMMARY OF DATA TARRED FIBER

No.	Follower	Revolutions per minute	Slip (per cent)	Contact pressure (pounds per inch)	Coefficient of friction
A	B	C	D	E	F
147	Iron	220	0.30	150	0.115
148	Iron	220	0.40	150	0.160
149	Iron	220	0.50	150	0.125
150	Iron	220	0.80	150	0.190
151	Iron	220	1.15	150	0.225
152	Iron	219	1.52	150	0.235
153	Iron	218	2.05	150	0.256
154	Iron	220	4.30	150	0.275
155	Iron	220	1.85	200	0.232
156	Iron	220	1.25	250	0.217
157	Iron	220	1.40	300	0.215
158	Iron	220	1.65	350	0.216
159	Iron	220	1.36	400	0.210
160	Iron	220	0.40	400	0.115
161	Iron	220	0.45	400	0.134
162	Iron	216	0.46	400	0.151
163	Iron	219	0.56	400	0.166
164	Iron	220	1.00	400	0.191
165	Iron	220	1.74	400	0.212
166	Iron	222	2.56	400	0.223
167	Aluminum	220	0.30	400	0.062
168	Aluminum	220	0.42	400	0.145
169	Aluminum	221	0.55	400	0.171
170	Aluminum	220	0.55	400	0.212
171	Aluminum	220	0.60	400	0.225
172	Aluminum	216	0.60	400	0.200
173	Aluminum	220	0.72	400	0.235
174	Aluminum	220	0.82	400	0.245
175	Aluminum	220	1.10	400	0.263
176	Aluminum	216	1.20	400	0.270
177	Aluminum	215	1.40	400	0.266
178	Aluminum	216	1.83	400	0.286
179	Aluminum	219	2.50	400	0.300
180	Aluminum	219	3.10	400	0.310
181	Aluminum	220	2.12	150	0.317
182	Aluminum	220	1.70	200	0.300
183	Aluminum	180	2.10	250	0.303
184	Aluminum	180	2.00	300	0.300
185	Aluminum	191	1.90	350	0.295
186	Aluminum	190	2.05	400	0.290
187	Type Metal	230	0.54	400	0.057
188	Type Metal	229	0.63	400	0.083
189	Type Metal	227	0.70	400	0.103
190	Type Metal	227	0.73	400	0.117
191	Type Metal	227	0.80	400	0.140
192	Type Metal	220	1.00	400	0.211
193	Type Metal	220	1.10	400	0.221
194	Type Metal	220	1.26	400	0.220
195	Type Metal	220	1.60	400	0.255
196	Type Metal	220	2.00	400	0.270
197	Type Metal	220	2.75	400	0.285
198	Type Metal	224	2.00	350	0.270
199	Type Metal	225	2.00	300	0.275
200	Type Metal	227	2.00	250	0.270
201	Type Metal	226	2.00	200	0.269
202	Type Metal	227	2.00	150	0.280
267	Iron	210	1.90	200	0.174
268	Iron	211	1.96	300	0.168
269	Iron	210	2.16	400	0.164

TABLE 5 SUMMARY OF DATA LEATHER

No.	Follower	Revolutions per minute	Slip (per cent)	Contact pressure (pounds per inch)	Coefficient of friction
A	B	C	D	E	F
203	Iron	215	0.65	400	0.113
204	Iron	212	0.68	400	0.086
205	Iron	212	0.86	400	0.109
206	Iron	212	0.94	400	0.120
207	Iron	211	0.95	400	0.137
208	Iron	211	1.04	400	0.153
209	Iron	212	1.10	400	0.160
210	Iron	213	1.13	400	0.137
211	Iron	213	1.35	400	0.183
212	Iron	211	1.35	400	0.176
213	Iron	216	1.56	400	0.163
214	Iron	215	1.60	400	0.183
215	Iron	208	2.00	400	0.200
216	Iron	212	2.40	350	0.245
217	Iron	210	2.30	300	0.244
218	Iron	212	2.20	250	0.237
219	Iron	209	1.92	200	0.225
220	Iron	213	2.00	150	0.213
221	Aluminum	211	0.64	300	0.115
222	Aluminum	209	0.80	300	0.160
223	Aluminum	210	1.12	300	0.201
224	Aluminum	213	1.40	300	0.233
225	Aluminum	214	1.70	300	0.260
226	Aluminum	210	1.50	300	0.267
227	Aluminum	210	1.85	300	0.279
228	Aluminum	209	2.45	300	0.310
229	Aluminum	210	3.00	300	0.313
230	Aluminum	211	2.30	350	0.320
231	Aluminum	211	2.00	300	0.305
232	Aluminum	213	1.90	250	0.316
233	Aluminum	214	1.92	200	0.348
234	Aluminum	215	1.92	150	0.380
235	Type Metal	212	1.90	150	0.412
236	Type Metal	213	2.00	200	0.400
237	Type Metal	211	2.10	250	0.389
238	Type Metal	214	2.35	300	0.361
239	Type Metal	214	2.00	350	0.350

TABLE 6 SUMMARY OF DATA SULPHITE FIBER

No.	Follower	Revolutions per minute	Slip (per cent)	Contact pressure (pounds per inch)	Coefficient of friction
A	B	C	D	E	F
240	Iron	211	1.75	150	0.546
241	Iron	211	2.15	200	0.549
242	Iron	210	1.70	250	0.550
243	Iron	211	1.90	300	0.512
244	Iron	210	1.70	350	0.505
245	Aluminum	211	2.00	150	0.535
246	Aluminum	211	2.20	200	0.527
247	Aluminum	211	2.26	250	0.522
248	Aluminum	211	2.10	300	0.520
249	Aluminum	211	2.10	350	0.523
250	Type metal	211	1.80	150	0.505
251	Type metal	211	1.95	200	0.516
252	Type metal	210	1.90	250	0.513
253	Type metal	211	1.75	300	0.490
254	Type metal	212	1.75	350	0.510

TABLE 7 SUMMARY OF DATA STRAW FIBER—IRON

No.	Speed		Slip (per cent)	Contact pressure (pounds per inch)	Coefficient of friction
	Revolutions per minute	Feet per minute			
A	B	C	D	E	F
255	107	450	2.15	200	0.446
256	107	450	2.06	300	0.443
257	107	450	2.02	400	0.412
21	200	836	1.80	200	0.436
26	165	690	2.02	300	0.405
28	211	882	2.12	400	0.410
258	800	3350	2.09	150	0.472
259	800	3350	2.05	200	0.480
260	800	3350	1.91	250	0.440

TABLE 8 SUMMARY OF DATA TARRED FIBER—IRON

No.	Speed		Slip (per cent)	Contact pressure (pounds per inch)	Coefficient of friction
	Revolutions per minute	Feet per minute			
A	B	C	D	E	F
261	107	450	1.88	150	0.290
262	107	450	2.06	250	0.289
263	107	450	1.90	400	0.287
153	218	910	2.05	150	0.256
156	220	920	2.00	250	0.240
166	220	920	2.56	400	0.223
264	800	3350	2.04	150	0.306
265	800	3350	2.10	250	0.287
266	800	3350	1.85	400	0.301

TABLE 9 COEFFICIENT OF FRICTION

	Coefficient of Friction when Contact Pressure is 150 Pounds Per Inch		
	Iron	Aluminum	Type Metal
Sulphite Fiber.........	0.550	0.530	0.315
Leather Fiber..........	0.515	0.495	0.305
Straw Fiber...........	0.425	0.455	0.310
Tarred Fiber..........	0.250	0.305	0.275
Leather..............	0.225	0.360	0.410
Straw fiber with belt dressing............	0.120	—	—

FOLDER 2

[illegible]

FOLDER 2

No. 1181

INDUSTRIAL EDUCATION

The Apprentice System of the New York Central Lines

By W. B. RUSSELL, NEW YORK

Junior Member of the Society

The necessity for an adequate recruiting system for the supply of trained mechanics is evident to all who are familiar with our present industrial conditions. The object of this paper is to present the details of a comprehensive, practical and workable apprentice system, which is already in successful operation, and which, because it is constructed upon carefully studied basic principles, can be made to work under all conditions and in any branch of manufacturing or repair work.

2 Efficient apprentice training is expected not alone to raise the grade of mechanics, and to provide from the ranks the necessary leaders and officers, but also to produce ultimately an organization in which men and officers alike can think intelligently, an organization replete with coöperation and efficiency; with its members bound together by association and by training; an organization fully equipped to meet the increased demands of progress and competition. Our large manufactories and railroads are suffering from a lack of knowledge of their men and the possibilities of these men. Large companies are too apt to go outside for their leading employees simply because they have no means of knowing whom they have in their midst capable of filling the important positions. It is not the mere training of workmen that is needed. We want also a system which automatically necessitates intimate knowledge of the capacity and possibilities of the material at hand. Nothing will reveal or cause ability and capacity to discover itself as will a well regulated apprentice system.

Presented at the New York Meeting (December 1907) of The American Society of Mechanical Engineers, and forming part of Volume 29 of the Transactions.

3 To train an apprentice and not to make use of him when out of his time is to lose the best results of the effort, and yet but few organizations at the present time are prepared to make intelligent use of graduate apprentices. The bright boy is blamed for leaving at or before the completion of his term, but the fault is largely due to the failure of his employer to appreciate his true value and to make further progress possible. It is not economy to spend three or four years perfecting a boy and then to let him go, and a continuance of such policy will ultimately kill the best apprentice system. Nothing less than a complete and radical change of policy is needed in most organizations to fit them both to attract and to hold apprentices.

4 The apprentice system as now organized on the New York Central Lines, was inaugurated on March 1, 1906, by Mr. J. F. Deems, General Superintendent of Motive Power, although evening schools for apprentices had existed for a number of years at several of the shops. The system here described has the hearty approval of both men and management. It is a cold-blooded business proposition, which has paid for itself from the start, and which has not a particle of philanthropy connected with it.

5 The general plan is two-fold and provides for shop instruction of the apprentice in the trade and for his instruction in educational subjects allied to his trade during working hours while under pay.

6 A shop instructor teaches the trade in the regular shop and on the regular work. As the majority of the apprentices at each shop are machinists, the shop instructor is preferably an up to date all around machinist giving instruction in the machinist trade, but with sufficient knowledge of the other trades, which may have apprentices, to be able to supervise intelligently apprentices in those trades. If the shop is small he gives only a portion of his time, while in a large shop his entire time is taken and he may require assistants. He must possess the necessary tact and be invested with sufficient authority to command the respect, coöperation, good will and confidence of all concerned.

7 The educational classes are taught by a second instructor who may be either a draftsman, an advanced mechanic, or a mechanical engineer. His previous education is of less importance than his ability to explain simple shop problems, and his appointment should be based as much on the possibilities of his development as on his actual attainments. Previous experience in teaching is not necessary, although experience in teaching evening classes may prove helpful. The ideal instructor is a man who can look at problems

from the stand point of the apprentice, who can work them out with the apprentice, and who can bring himself to realize and appreciate the difficulties as they present themselves. This type of instructor may often be the man who is obliged to study nights to keep ahead of his class. The educational instructor should spend only a part of his time in teaching, and will be able to keep the educational work closer to company practice and himself in line of promotion in the organization if he at the same time retains a position in the shop or in the drafting room. Where the educational work is sufficient to require the full time of one man, an assistant should be provided and both should give part time to the work.

8 The fact that the shops of the New York Central Lines are widely separated, necessitated the organization of a central department. Mr. C. W. Cross, who was well known throughout the New York Central system as the master mechanic of a large division, was appointed as superintendent of apprentices to have general supervision of the work. The educational features were delegated to the author. The central organization was also desirable to procure uniformity of effort and to prevent waste of time and energy on unprofitable experiments. The problem of making the men of the future is one of such magnitude, and the questions arising on a large railroad system are so numerous that it is necessary to have one or two persons who shall give their entire time to this work.

9 The plan is now in operation at the nine larger shops of the system and already includes about five hundred apprentices. A uniform set of regulations has been adopted showing the classes of work in the shop and the time allotted to each class. These regulations have been made sufficiently flexible to suit the various conditions in different shops, to insure the prompt movement of all apprentices and yet to allow more rapid movement where special merit warrants. Uniform apprentice certificates are issued at the completion of the regular course which entitle the holder to preference in employment at all shops of the system.

10 All of the work done by the apprentices is a part of the shop output. The shop instructor is present to make each machine run at its best efficiency, even when handled by a "green" apprentice. The apprentices are still responsible to the foreman as formerly, but the foreman is relieved of the necessity of instructing them and is left free to run his department. The shop instructor passes on applicants for apprenticeship and in connection with the educational instructor recommends dismissal if unsatisfactory during the first six months. The shop instructor also arranges the changes of work in conference

with the foreman. He keeps fully informed of the conditions existing in the various departments of the shop; he is in close touch with the foremen and gang bosses; he knows when and where the stress of work is heaviest, and in making suggestions and recommendations he takes these matters into account. His position in the shop is such that his judgment is accepted by the foreman, and his recommendations followed by the shop superintendent. His personality is such that he inspires the respect, and at the same time invites the confidences of the apprentice. From the nature of his work he is kept in touch with the latest shop practice and is in line of promotion in the shop organization.

11 Class room instruction is largely individual, as the same class may contain apprentices just starting and others nearly out of their time. Educational ideas have been reversed. Much that is dear to the mathematician and physicist has been discarded. The work is so arranged that each apprentice may go as rapidly or as slowly as his ability allows. All principles are handled through shop problems and must have practical bearing. Class work is closely adapted to shop conditions. The problems are worded in the language of the shop. The whole scheme of education is simple and more elementary than usual, although it is made to include many principles of mechanics, strength of materials and steam, usually taught in technical schools. In fact the course of study fits the conditions, and the conditions are not those imagined by most educators.

12 Text books cannot be used directly for apprentice instruction even if suitable books could be found, as the average apprentice has a strong aversion to books. The literature for such instruction is yet to be written. One or two books are now available for reference, but the bulk of this material must be in the form of separate sheets, given out one at a time and arranged to advance gradually.

13 The chief features of the educational work are mechanical drawing, which is made the back bone of the course, and shop problems which include the other branches. The drawing is arranged to start directly on working drawings of actual machine and locomotive parts and yet to advance so gradually that even a dull boy can make headway. No time is taken for pure theory, and skill in drawing lines and making letters is obtained incidentally while making useful drawings. Blue print sketches are used to assist the instructor, but these are drawn so that they cannot be copied and each sketch leaves more or less to be worked out by the apprentice.

14 Mathematical problems as met with in a shop, or for that matter in every day life, do not come classified with the rule at the

top of the page. They are not even divided into arithmetic, algebra and geometry, and apprentices often meet problems so mixed in with facts, and so combined in the practical application of natural laws, that in many cases they do not appear to be mathematical problems at all. Shop problems taken indiscriminately from practice and put before apprentices would result in confusion and failure, but it is possible by a careful selection and adaptation to get together problems clothed in every day language, which are practical and useful and which, though actually classified and to some extent graded, do not show the classification. The terms algebra, arithmetic and mathematics are never used, and the sheets are not divided according to subjects. A running review is maintained by constantly introducing problems on the ground already covered.

15 Interest is further held by varying the standard of difficulty and mixing the easy and the hard problems as they are apt to come in practice. In getting together these problems, all departments of the railroads and many outside sources of information have been utilized. Company drawings, standards and records, facts and data from the technical press, suggestions from motive power officers, problems directly from the shop and drafting room, hints from instructors and points picked up in conversation with foremen and mechanics have alike been used. Experimental apparatus is being installed in the school room so that natural laws may be illustrated, but not necessarily proved, as it is the intelligent use of these laws, and not their proof which is desired. Models and actual machines are used for illustrations. In gearing, the gears are fitted on to a screw cutting lathe in the school room and revolved as a check to the method of figuring them. Locomotive valve setting is introduced by a thorough course in valve setting on a stationary engine located in the school room and arranged to run by compressed air. Lectures are not well suited for apprentice instruction and when used must be short and must take the form of talks or recitations.

16 Classes are held from 7 to 9 o'clock in the morning; each apprentice reporting for two mornings a week. The apprentices ring in at the shop and then come to class rooms located on the shop property, where they are under shop discipline. At 9 o'clock they report again in the shop. Compulsory evening classes for apprentices have never been entirely satisfactory, but the plan of holding classes during working hours has been used by the British Admiralty for 60 years with entire success. Home work is expected on the problems.

17 An elaborate system of reports from both instructors is made

to the local shop officers who forward them to the superintendent of apprentices. These reports show first, the ability at the trade, second, the disposition and personality of the apprentice, and third, the standing in class work. The instructors are at all times required to know the standing of each apprentice, thus making examinations unnecessary. Special emphasis is placed on the personal touch maintained between the instructor and the apprentice with a view to determining the type of work or branch of service for which the boy is best suited.

18 This movement differs from most efforts to better industrial conditions, in that it starts at the bottom in marked contrast with the common practice of providing special advantages for the especially bright. In this respect it is not unlike the type of training proposed by Mr. M. P. Higgins in a paper before this Society in 1899. The rank and file are not touched by special apprenticeship or special courses at high schools. Industrial education must start lower down the scale, and the genius will be the first to profit by the advantages offered. The problems designed for a boiler-maker apprentice have been found quite useful with college graduates and the problems used for apprentice classes have been used with equal success in evening classes for foremen, mechanics and inspectors.

19 Experience has proved the desirability of keeping boys in direct contact with the shops from the very outset, in which point the plan differs from that of Mr. M. W. Alexander of the General Electric Company as described in his paper of last year.

20 The immediate and direct results of the apprentice system have been, increased output, (notwithstanding the four hours per week spent in class) less spoiled work, ability to read drawings, to lay out templates and to make sketches, a better grade of apprentices, increased interest in the work, suggestions of apprentices as to improved methods and tools, draftsmen for company drafting rooms and apprentices fitted for special work as needed. Local officials have everywhere been quick to note the benefits of apprentice training, and are unanimously enthusiastic and interested. One immediate result of the opening of the apprentice schools was the request from foremen and mechanics for educational classes of a similar nature, which resulted in the organization of self supporting evening classes at seven of the shops taught by the apprentice instructors, using practically the same courses of study as provided for apprentices.

21 The essential points in the inauguration of an apprentice plan like that described may be stated as follows:

a The full endorsement and the support of the management from the president down, and the hearty coöperation of all concerned. Without this the movement is sure to fail.

b The necessity of preparing a shop organization to make use of the apprentices who are thus trained, so that bright young men will be attracted to start on an apprenticeship which will graduate them into an organization where ability will be recognized, and where advancement will be possible.

c The selection of a shop instructor, possessed of the necessary skill and tact who shall give a portion or the whole of his time, according to the size of the shop.

d The selection of an educational instructor who shall have sufficient originality to cut away from current educational practice and to meet the local needs of the apprentice in his own way.

e The outlining of a course of study which will closely combine the theoretical and practical, and which will be framed for the dullest apprentice and not for the high school graduate.

f A recognition of the fact that the best results can be obtained only when the instruction is on the shop property and under shop control and that technical schools, trade schools, correspondence schools, high schools, Y. M. C. A., or other outside agencies, cannot satisfactorily meet the needs of the rank and file of apprentices.

g The use of a room for drawing and class work near the center of the shop property.

h A realization that the plan can be installed in most shops with talent already employed.

i A recognition of the fact that instruction must be given during shop hours and that evening classes for apprentices are unsatisfactory.

j Industrial organizations are composed of men, not machines, and in the long run, no organization or department can prove really efficient which does not make allowance for the full development of its men and which does not count on the value of the personal touch in developing a proper loyalty and efficiency.

k The shop management must be prepared to provide evening classes self supporting, or nearly so, on account of the

fees charged, for the present foremen and mechanics who are sure to ask for an opportunity to obtain educational training similar to that of the apprentices.

22 No previous reference has been made to the most important principle underlying apprentice training. In addition to teaching the apprentice a trade and teaching him to think, it is vitally necessary to aid in the development of his moral character and in his loyalty to the right. These objects do not, from their nature, permit of immediate demonstration of success. They are, however, vastly important and the character side of the problem is, in the long run, the larger side. It would require an entire paper for its full treatment. No apprentice plan can possibly succeed if this part of the problem is not uppermost in the minds of those in charge. Neither the employer nor the community has anything to fear from the right-minded, conscientious man who thinks. Much may be feared from one who is not conscientious and right-minded or one who permits others to do his thinking. The author believes that the value to the employer, the community and the country of the influence of intimate association between apprentice boys and big-minded, "broad gage" instructors cannot possibly be over estimated. In comparison with this influence mere details of the apprentice plan are absolutely insignificant.

DISCUSSION

Mr. C. W. Cross The system of apprenticeship described by Mr. Russell is the result of years of experience and experiment by Mr. Deems before he established the plan in March 1906.

2 The foundation principles of the plan have stood the test of time and the only changes found necessary have been in the way of additions to the course. There is more enthusiasm now than there was a year and a half ago. It means that in future the shops will be supplied with workmen who have been trained in the theory and practice of the business, and the efficiency will be correspondingly increased.

3 The need of a better system of training mechanics for the railroad service is imperative, and I think need not be argued with any one in touch with the situation. The railroad company receives direct benefits by having the men quickly made familiar with the standards of practice. They are brought into close contact with the drafting room and also into intimate relations with the shop drafts-

men. The mutual understanding between the company and the men is greatly improved. The ambition of the men is aroused.

4 The recent awakening of interest in industrial education and the inquiries and observations from all directions indicate that other railroads and manufacturing concerns are now giving this subject the consideration it deserves and that the day is not far distant when each company will have a fully equipped apprentice system as an integral part of its organization.

Mr. Geo. W. Rink In establishments where it is necessary for mechanics to work with drawings, in order to insure interchangeable parts of machinery and also the production of new work accurately, as laid out by the draftsman, it is absolutely necessary that the young men who are growing into manhood and learning the various trades be given the necessary instruction in drawing which will permit them to produce the work accurately and speedily, and, at the same time, reduce the responsibility of the foreman so far as explaining the drawings is concerned; thus giving him more time to consider other matters which may be more urgent or important.

2 Since the establishment of correspondence schools and free evening schools in our larger cities it has become possible for mechanics who are anxious to advance themselves in their chosen field, to obtain a comprehensive knowledege of mechanical drawing and elementary mechanics. While there are a few who have taken advantage of this course, there are still a very large number who could not avail themselves of these opportunities. The result is that a very large majority of mechanics today do not understand drawing and never will understand the subject until they have been compelled, while serving their apprenticeship, to study. This deficiency is quite apparent in almost any railroad repair shop of the country. The author, who has served his apprenticeship in such a shop, recalls the fact that most drawings of locomotives and their details, at that time, were kept in the superintendent's office, and occasionally a print for the mechanic to work from would find its way into the shop. Repairs were made in a haphazard sort of way. If a certain part of an engine was giving trouble, it was repaired in one way on one division and other methods would probably be tried out on the other divisions. The result was that eventually no two engines of the same class would be alike, due to difference in ideas of different master mechanics.

3 Where in years past an occasional drawing would be seen in a railroad shop, in passing through a modern shop, you will see draw-

ings on almost every machine and work bench. The majority of young men seeking positions in railroad shops have had little or no training in drawing or the principles of mechanics; and, in order that these young men may become productive and efficient mechanics, it is the duty of officials to see that schools are established and proper instruction given, so that the future mechanics may be efficient.

4 With this object in view, the Central Railroad of New Jersey established in October 1905, at its principal shops at Elizabethport, N. J., a school for blacksmith, carpenter, machinist, pattern-maker and boiler-maker apprentices, which has proved of great benefit to the company. The school has been evolved by Mr. B. P. Flory, mechanical engineer, Member of the Society, acting under the direction of Mr. Wm. McIntosh, superintendent of motive power.

5 The organization of this school was accompanied by a ruling that all boys applying for positions as apprentices must pass an examination in reading, writing and arithmetic, and present three letters of introduction from business men in the community in which they reside, testifying to their moral character. The minimum age limit was established at 17 years. All of the apprentices are required to attend school throughout their four years of apprenticeship. The school isdivided into three classes, meeting, during working hours, from 12:45 to 2:45 p.m., on Monday, Wednesday and Friday of each week, except during July and August. Each class consists of 20 apprentices, making a total of 60, each apprentice receiving two hours instructions a week. The company has fitted up a school-room in its storehouse building, and has supplied tables, benches, blackboards and all the necessary drawing boards, "T" squares and other supplies, excepting the drawing instruments, scales and triangles.

6 The method of instruction is as follows: The boys are required to draw from models and castings. They are first put to work making free hand sketches of wooden blocks of various shapes in order to acquire a facility in representing objects which are afterward laid out to scale on drawing sheets. This is followed by more advanced work which eventually gives the apprentice a thorough knowledge of tools, and enables him with little effort to read, make and work from drawings. Text books are dispensed with, as it is necessary to give instructions as the individual needs of each student require.

7 Typewritten sheets, in blue-print form, are distributed among the students, as a basis of study in connection with the practical work placed before them. These treat of elementary geometrical problems, formulae, pulley and gear speeds, screw threads and other matters of interest to the student.

8 The question may be asked, "Does it pay the company to do all this for the apprentices; is it not probable that the majority of these young men will leave the service of the company and procure positions elsewhere?" The facts are, that in a district where there is a demand for mechanics it is a difficult matter to retain young men until the completion of their apprenticeship. The situation at our plant, from 1905 to the present date, is as follows: 144 apprentices were on our rolls during that period. 21 resigned after serving one to four months; 8 resigned after four to twelve months service; 8 resigned after serving one year; 6 resigned after serving two years; 6 resigned after serving three years; 6 resigned after completing the apprenticeship, and 18 are in service as machinists, having completed their apprenticeship; 7 were discharged, 7 placed on a probation period of 2 months, and 57 are now in service, time not completed. The boys who served from one to twelve months and then resigned either lived too far from work, were not strong physically, or did not care to learn the trade. The majority of apprentices remained in service after completing their apprenticeship; and there is no doubt that the knowledge gained by these young men, while attending the apprentice school, has helped them along considerably with their work, and the company certainly has been benefited.

9 By selecting the brighter apprentices, boys who show an interest in their work, and giving them employment in the drawing room for a short period, it is possible to recruit from the shops young men, who, if they will pursue home studies in connection with their work, can eventually fill positions as foremen or designers. This plan is also being followed out by the Central Railroad of New Jersey.

Mr. Luther D. Burlingame In considering the apprenticeship or trade school question there are two distinct objects to be attained; one is the raising up of foremen and managers—those who can carry on the executive work of the shop, and the other is the training of expert workmen who can do a good job and who will be proud of doing that job satisfactorily. One great lack in both the trade school work and the apprenticeship system, as usually carried on, is the tendency to create in the boys the ambition to become foremen only rather than some of them expert workmen of the old type.

2 Mr. Russell's paper shows that the apprenticeship system is not a dead issue, as has so often been pointed out by our journals, for many concerns are taking it up in a systematic way. The works with which I am connected—The Brown & Sharpe Manufacturing Company—has had an apprenticeship system in successful operation for

more than fifty years. Our business has been developed on this basis and the men that have been thus trained, have, in a large measure, been a vital factor in our work. We are today however looking toward developing in addition workmen who will be satisfied to become good workmen, not with ambition to become managers, but taking pride in doing a good job and finding their satisfaction in life in being expert machinists.

3 I am glad to see that efforts are being made to give boys who have had a very limited school training a brighter outlook upon life; to make expert workmen of those who would otherwise be only clerks or laborers. Such a development will give a great impetus to our mechanical work. This is where our greatest need is at the present time and where the remedy should be applied.

Mr. Henry Gardner Mr. Russell's statement of the influence of big-minded, broad-gage instructors receives my hearty endorsement. A bright, energetic shop man, mature enough to be serious and to have the welfare of each boy at heart—preferably a man who has served his apprenticeship in the shop and in the classroom—is the ideal instructor. This man's life work is in the shop, and the whole of his influence is exerted to direct the boy toward the shop as the goal at the end of four years' study.

2 I am not in accord with the policy that makes mechanical drawing "the backbone of the course." Drawing should be emphasized only during a period sufficient to enable the boy to make good working drawings and sketches—perhaps during the first two years—the remaining two years being devoted to problems demonstrating shop practice, such as valve setting, setting driving box shoes and wedges, quartering driving wheels, screw cutting and gearing. Models for studying the Stephenson and Walschaert valve gears might be employed, and methods devised, largely eliminating the drawing, for studying the working principles of the air brake, injector, lubricator, intercepting valve and other important locomotive accessories, all of which are repaired in the shop.

3 It would be beneficial to specialize during the fourth year, after the plan in vogue in some of the leading technical schools.

4 Advantages additional to those already cited, are: The boys are taking more and more responsibility, and the confidence of the foreman in the boys is constantly increasing. Apprentices are chosen to set valves, put up shoes and wedges, make templets and jigs and do many kinds of high-grade work. The gain to the employers from the noticeable increase in ambition, manliness, self-confidence and

sense of responsibility cannot be questioned. The apprentice boy of today is undoubtedly the "timber" for the future shop foreman.

MR. H. L. GANTT We are much indebted to Mr. Russell for his admirable description of a system of industrial education which seems bound to produce good results.

2 The shop instructor is a most valuable man, whether the shop contains apprentices or not. The writer has been familiar with him for twenty years, and has not only often been one himself, but has spent a great part of his time during recent years training shop instructors. The shop instructors who have been most useful to the writer are not so often those that have the necessary tact, as explained by Mr. Russell, as those that have the necessary firmness. More good training can be gotten out of the every day work of a shop than out of any other school, but to make such training available, the orders must be given as tasks, and each task must be specific as to:

a What is to be done,
b How it is to be done, and
c The time allowed to do it.

3 A proper instructor sees that the recipient of the order understands exactly what is to be done and teaches him how to do it in the time set. Such a scheme of instruction involves a means for task setting and a means for inducing the workman to perform the task. The task should be set only after proper study by a capable man, and the method of performing it should, whenever possible, be written out, showing the important steps in their proper order with the time needed for each. Such descriptions or "instruction cards" are of great assistance to the instructor, and the more intelligent workmen readily learn to follow them.

4 So much for the task and the instructions. How to make the workmen perform the task is another question. In dull times when men are badly in need of work, it is often possible to make the performance of the task a condition of employment, or a piece price may be set.

5 If however the operation is one often repeated and one at which a workman may acquire skill and speed with repetition, the task should be so much greater than an ordinary man can do at once that he is apt under either of the above conditions to give up the job. On account of this condition of affairs the writer devised his system of paying every man a day rate, and to those who succeed in accomplishing the task, an additional amount, or *bonus*.

6 The success of this method of instructon has been most marked. The results have been:

a An increase of output,

b A reduction in cost,

c The development of highly skilled workmen, who in turn have yielded an unusually large crop of good foremen.

This bears out Mr. Basford's statement in his discussion of Mr. Jackson's paper[1] that if we have a good organization as to rank and file, the captains and subordinate officers will not constitute a problem.

7 The scheme described by Mr. Russell, good and useful as it undoubtedly is, is applicable only to special cases and to rich and powerful corporations.

8 What the writer has described is in successful operation in one shop containing ten workmen, several between twenty and fifty, and others having a larger number. These shops represent four industries: wood, cotton, iron and steel.

PROF. GAETANO LANZA That the apprenticeship system of the New York Central Lines must accomplish a great deal of good there can be no doubt, and it may be the best that is possible in shops so organized. Whether it is conducive to retaining the best men can only be answered by a longer trial than one year.

2 It appears that the course given to the foremen is nearly identical with that given to the ordinary apprentices. For foremen who have not already covered the ground, it will doubtless be of advantage to take the course and a more efficient one will probably be necessary for those that have completed it.

3 It is evident that the education given to any class of men, should be the best for that class, and not that of some other class.

4 It is my belief that apprentices who have had a good course in the mechanic arts are more useful, and advance more rapidly than those that have not had such instruction, and that they would accomplish more if they were first trained in the processes instead of working at the products that are for sale.

5 How many shops would be willing to incur the expense necessary first to give instruction in the processes, and subsequently experience in the shop is an open question. Those pursuing such a course, would, I believe, be the gainers in the end.

[1] "College and Apprentice Training" by Prof. John Price Jackson, published in this volume.

6 The amount of theoretical or literary instruction that can be absorbed by the boy who would usually present himself for such an apprenticeship is, moreover, small, and the course should be arranged with this fact in view. But in order to accomplish the best result, and to make him a thinking and not a rule of thumb man, the greatest care should be taken to limit what is given him to what he can do thoroughly, as there is always a strong temptation on the part of both teacher and pupil to overdo, to do more, sometimes resulting in bad mistakes.

7 When it comes to a school for foremen, the paper presented by Professor Park gives the practical results that have been obtained by a course which has been in existence for four years.

8 Another class who need a different course are the graduates of good technical schools. They are aiming to become engineers or managers. That they should perform some of the lowest grades of work, even cleaning out a smoke box, goes without saying, but the frequency of the changes in their duties should depend upon their competency.

9 To tax their powers they should also be given problems to work out, the solution of which will give them a broader view of the departments.

10 In general, it is necessary to specify what class of men the course is intended to educate, inasmuch as a course suitable for one may not be at all suitable for another class of men.

Prof. A. L. Williston It is an important step in industrial education to have a large railroad company like the New York Central undertake with thoroughness and seriousness the systematic instruction and education of the men in its large shops.

2 The various schemes for training working men presented to this Society have necessarily differed widely, for industrial education is many sided and requires many methods of approach, each one adapted to its particular set of conditions and requirements. The new movement by the New York Central Lines is one more important step toward the solving of one of the most gigantic problems that confronts our profession today.

3 One or two points are of special significance. First, those interested are able to get hold, without any question, of the right type of men to be employed in the railroad shops. In some methods there is no way of being sure of this. Young men are being educated to be machinists, but after their training is completed, it is frequently found that much of the time has been wasted, because they decide

to enter some other occupation. In the plan described this question is entirely eliminated.

4 The second point is the perplexing problem of providing some means of support for the young men during the period of training. By this plan men receive their regular pay as full time apprentices, which is sufficient for them to live upon. This is most important, as the young men who actually go into the machinist's trade generally come from homes from which they can expect but little or no financial support. Consequently any plan for training machinists must, if it is to succeed, include some such provision.

5 The third point is that the company's time is used for educating these young men in class rooms with trained and paid teachers who are especially chosen because of their particular fitness and who are expected to develop courses of instruction that will accurately fit the needs of men in each of the shops. The teachers have had similar experience; they thoroughly understand the conditions, and have every opportunity for making the work thoroughly practical.

6 The very best hours in the day and in the week are chosen. In no better way could the company say to its men that they regard it of more importance for them to learn, if any difference is to be made, than to work.

7 In the many systems that have been heretofore suggested, the time for education has been limited to six months or a year, or other comparatively short periods. In this system the instruction is distributed over four years. In four years, with five hours of regular instruction each week, a great deal can be accomplished, more than could be done with the same number of hours concentrated into a shorter space of time.

8 The system described has many excellent points. In the classroom there is developed an atmosphere of inquiry and ambition which ought to stimulate the men to do their very best and arouse high ideals; and in the shops there is a special instructor whose duty is to be ready to give individual aid wherever it will do most good; who sees that each individual gets as large a variety of practical experience and also profits as much as possible from each of the tasks assigned him. In such a system we expect and feel a growing coöperation between the corporation and the employees in the shops, which is decidedly increasing their efficiency.

9 It will doubtless take time to develop the courses of instruction to fit best the needs of those for whom they are intended; it will take time to find and train the men who will make the most efficient instructors; but gradually these difficulties may be overcome. In one or two

other particulars, too, the work may be somewhat handicapped. Usually young men attend trade schools, from a desire to learn and because they feel the need of the training. In the plan described they go because the rules of the shop require it. In many trade schools, drawing their students from the whole of a large community, it is often possible to get a body of young men far above the average in intelligence and in ambition. Here such a picked body of young men is impossible. The railroad must deal with the rank and file of those who enter its employ.

10 These are a few of the difficulties that must be met. Another is that the shop and the class instructors, surrounded as they always must be by the big commercial organization, will find it difficult to create among the young men who are under their charge quite the same kind of *esprit de corps*, that they would be able to obtain from their students if they were somewhat less dominated by the commercial atmosphere of the shop. In spite of these difficulties, however, the plan which Mr. Russell describes in his paper has many good points in its favor, and very far reaching possibilities of application.

Mr. H. F. J. Porter This paper is really an appeal for the education of the manager; of all officials from the president down.

2 The paper and the discussion emphasize the necessity of securing the loyalty of the organization. This loyalty cannot be elicited unless the management inspires confidence by assurance of fair treatment and reasonably steady work. There is no use in educating the employee if at the first sign of a financial flurry the works are shut down or the payroll materially cut.

3 Notwithstanding the establishment by colleges and technical schools of courses in economic methods of organization and management in response to the urgent demand for men to take control of industrial enterprises, there is still a crying need for the broad dissemination of a knowledge of business principles.

4 From time to time suggestions have been made, looking toward the establishment of a national society of business managers. Perhaps this period of suffering due to the bad business methods of the managers of large corporations, may be found the psychological moment for inaugurating such an association.

Mr. Frederick A. Waldron It would seem that an apprenticeship is the same to a young mechanic as the college course is to the engineer; it teaches the young man how to learn. Does not the greatest scope of industrial education lie in the broadening out of the apprentice, journeyman, foreman and superintendent along those lines which will compel him to consider manufacturing *as a business* and not as an aggregation of technical or mechanical problems alone?

2 The young industries of this nation may well profit from the thoroughness of the older nations, who carefully consider the minutest detail. Impress upon the young man the value of detail.

3 The watchword of the apprenticeship training system should be thoroughness rather than speed. Teach thoroughness at the start and speed afterward. This can only be done by a sufficient number of competent instructors placed over a limited number of apprentices. Methods of handling tools and machines and the reasons therefor should be carefully taught. Passing through the shops of a concern having a very complete apprenticeship system, the fact that impressed the writer most was that very few of the apprentices could take hold of a file and manipulate it in the proper manner. Upon inquiry it was found that they had never received thorough detailed instruction in the use of a file, either at the bench or lathe.

4 I do not agree with the statement made in paragraph 6 of Mr. Gantt's discussion, in which he refers to the assertion that captains and subordinate officers will not constitute a problem." This will ever be a problem, as the personal equation cannot be eliminated, and the personality of the leader inspires the rank and file with confidence which begets enthusiasm, and without the latter the highest efficiency cannot be obtained.

5 It is equally important that shop ethics should be thoroughly taught the apprentice. He should be trained to a sense of honor and a standard of personnel so high that those entering the course have not only the desire to be good mechanics but broad, upright, honest and high-minded men.

6 By beginning along these lines a desire is created for a broader standard of manhood, and duplicity, politics and petty jealousies will almost disappear.

MR. W. J. KAUP A broad and successful work covering so wide a range as that of the New York Central Lines, where the elevation of 6000 or 7000 men is involved, is worthy of the support of all men. At the same time it is too much specialized to meet all of the demands for industrial education.

2 The ideal system is one which develops the man as a *man* and not as a *machine*.

3 To train a man under the same system and in the same atmosphere in which he spends his working hours is not an easy thing to

accomplish. You may be able to increase his earning capacity, but the largest growth and the best results do not come from putting the men in competition with each other. The writer has found that we must first put the man in competition with himself.

4 This requires (*a*) an inspired teacher who can create inspiration through his complete knowledge of the intent of the course, through his control of men and through intimate contact with the students; and (*b*) an opportunity for the man to "try himself out," unhampered by any suspicion that he is not getting a "square deal."

5 We must return to our former ideals; turn the trade schools back toward their original purpose, individualize the students of our apprentice schools and give them confidence in themselves and pride in their work and their loyalty.

6 The New York Central Lines in their own way—philanthropic, magnificent—are sacrificing 30 000 or 35 000 hours a week in the cause of pure education. Other companies are experimenting with other apprenticeship courses. All have the same end in view, but, of necessity, too much attention is paid to specialization. The supply is far too limited, and the field covered too narrow to meet the general demand. What is needed is an industrial educational system devoid of specialization.

MR. OSCAR E. PERRIGO The writer heartily approves of this apprenticeship plan and recognizes that it is the result of much study and experience by men eminently qualified for the work.

2 The apprenticeship contract for a four year's course should contain a provision whereby the bright and active apprentice may, by exceptionally good work, shorten this period to three years. The following plan is suggested. Divide the four years' course into eight periods of six months each. Fix a rate of pay for the first period and add one cent per hour to this rate at the end of each period. The system of reports should show a percentage of efficiency for each month. The average of this percentage for the first period should determine the time to be deducted from the succeeding period as a reward, and so on through the course.

3 There might well be a provision in the contract whereby a percentage of efficiency below a certain point would lengthen the regular term of four years. But practical shop men are likely to reply to this that the apprentice who cannot learn the trade in four years might as well be dropped from the roll.

4 In the practical work of the shop it is often found that one of the most difficult things for the technical college graduate to do is to ***think***

outside of the book. It is just here that the system formulated by Mr. Cross and Mr. Russell attains its greatest and most useful result. Text books are cast aside, and the apprentice is taught in a practical way *to do his own thinking.*

5 The shop instructor, directing the practical education, the educational instructor, teaching technical matters in simple every day language without reference to texts books, and the shop foreman, should constitute a committee whose recommendations regarding the progress of the apprentice, when approved by the shop superintendent, should be final.

Mr. Arthur L. Rice The key-note of this problem is in the last paragraph of the paper, which should have been the first one, namely, that if we are to succeed in producing a good and useful workman it is vitally necessary to aim at the development of moral character and loyalty to right. Before a full day of conscientious work is secured from the coming mechanic he must grasp the meaning of duty to himself and to his calling.

2 The courses as outlined seem to be admirable. Experience teaches that, in order to arouse the interest of the average man, it is necessary to employ practical problems. The statement of the laws governing falling bodies is of little interest; but the solving of a problem on the pile driver catches the attention at once, and brings the desire to know the principles underlying the solution.

3 In industrial education the proving of scientific laws has however, no place. The men should be taught how to use the tools of both hand and mind—not how to make the tools of either kind; and for the purpose there is quite as much of educational value in the using of the tools as in the making of them; as much in the solving of the steam engine problems or the setting up of a gear-cutting machine, as in proving the laws of thermodynamics or of kinematics.

4 Instead of text books is to be recommended the study of technical journals and mimeographed or printed instruction leaflets, as the best means of keeping abreast of the progress of the art.

5 The value of a technical education from a dollars and cents standpoint is unquestionably proved; but so far as the economic problem goes, we have yet to adapt our means to the end so that there shall be the least loss of time and money to the individual and the community. Putting six years of preparatory and engineering college training on a boy who wants to be and is fitted by nature to be a department foreman, does not agree with our ideas of commercial efficiency; and, though we may have made a somewhat better citizen,

it is questionable whether the really usable amount of training in technical matters, supplemented by greater attention to business methods, the laws of economics, and the principles of good government would not make a broader minded and more efficient shop superintendent than even the best of our engineering college courses.

THE AUTHOR The statement has been made that the plan described is applicable only to special cases and to rich and powerful corporations. The methods of shop instruction would appear to be quite general in their application. Mr. Gantt has called attention to the value of the shop instructor for training men as well as apprentices. A number of railroad officials have expressed the opinion that all departments of the railroad should be recruited by similar methods. Of the school training it may be said that all industrial education is special in the sense that the illustrations and problems are selected in each case from the shop or industrial environment. This does not in the least interfere with making the training general and even to some extent cultural in its results.

2 As to the scheme being applicable only to rich and powerful organizations, the small shop has the advantage in dealing with apprentices. There is then no occasion for a central organization like that required by a large railroad. In the small shop there is the added advantage of closer personal contact between employer and employed, and often there is less specialization. Some of the most successful solutions of the apprentice problem are at present being worked out in small manufacturing plants and small railroads, and results are being obtained which it will be hard to equal in large corporations. It is expected that the system described will ultimately be extended to shops having five or more apprentices.

3 The point is well taken that there is danger of too much emphasis on mechanical drawing and of too little upon problems demonstrating shop practice. It was necessary at first, however, to emphasize the drawing in order to demonstrate at once to the shop authorities the value of the school work, and this plan has been entirely successful in producing immediate benefits. More attention is now being given to other subjects and additional equipment has been procured for problems and experiments. In apprentice courses, the danger to be guarded against, is not that of over education, but of misdirected education, as there cannot be too much training of the right kind.

4 The discussions by Professor Lanza and Professor Williston should remove any misapprehension in the minds of educators or

others who imagine that apprentice training is intended to rival that of technical schools. Apprentice education is in a field by itself and is at present supplementary to other types of instruction.

5 The movement has been characterized repeatedly as philanthropic. While it may be true that the first idea of the originator of the plan was one of philanthropy, and while it is true that all of the instructors do much more than that for which they are paid, it is nevertheless a fact that the movement is a plain business proposition and would cease to exist if it were not. The reason that the plan looks like philanthropy is because of the economic fact that everything which tends to give an apprentice added skill, breadth of view or development of character makes him that much more valuable to his employer. That which is best for the boy is best for the company. It is thus possible for a broad-minded, far-sighted shop management to develop a boy in the lines for which he is best adapted and to the full limit of his ability, and still to do this as a business proposition. Training the sons of employees in such a way is a common point of agreement between men and management.

6 Professor Lanza has hit upon the keynote of the class work when he says "the education given to any class of men should be the best for that class." Professor Williston calls attention to the fact that the railroad is dealing, not with a picked body of boys, but with the rank and file. The railroad is giving that which the public school has failed to give, an education by which a boy can earn a living.

7 In spite of the obstacles mentioned, the *esprit de corps* is not so different from that in other schools. Rivalry between schools is keen and is fostered by visits of instructors and boys to other shops of the system. Apprentice clubs are the order of the day, with ball teams and inter-shop games.

8 Mr. Kaup says that what is needed is an industrial educational system devoid of specialization. The author would agree with this in so far as it means that the State should do much that the manufacturer and the railroad are now forced to do. However, when the State does take hold of such training it will be difficult to find a plan founded on educational principles more broad than the plan described, in which the methods and much of the subject matter is of universal application and is so regarded by the best educators. It may be of interest in this connection that one city of the Middle West is adopting the same methods and portions of the apprentice drawing, problem and physics courses for its public school system.

9 It is well to realize that whatever may be the ideals of apprentice training, any plan is doomed to failure that does not take into

account actual commercial and industrial conditions. While there is a field for all types of industrial education it remains a fact that comprehensive apprentice training is destined to play no small part in the solution of our present industrial problem.

No. 1182

SIR BENJAMIN BAKER

IN MEMORIAM

Sir Benjamin Baker was born at Tondu, Glamorganshire, March 31, 1840. At sixteen years of age he was apprenticed to the North Abbey Iron Works, South Wales, remaining with them four years. On leaving these works he aided in the erection of the Victoria Station and the Governor Road railway bridge. Upon the proposal of Sir John Fowler to construct an underground Railway, which was received with great opposition, Mr. Baker spent much time in the study of theoretical mechanics which resulted in his work on "Long Span Bridges" and "The Strength of Beams" published in Engineering (London). In the former article the possibilities of the Cantilever type of bridge with a central supported girder, worked out in later years in the Forth Bridge, first received recognition. He was the author of several articles on "The Strength of Brickwork" published in 1872, and "Urban Railways" published in 1874. He was engineer of the City and South London Railway, the first of the underground lines in London. He had complete control of constructing the District line from Westminster to London. In conjunction with the contractor he designed the cylindrical iron vessel in which Cleopatra's needle was transported to England in 1878.

One of the existing monuments to his work is the design and construction of the Forth Bridge in which he carried out the theories set forth in his articles on "Long Span Bridges." While engaged in this work he made a series of experiments on the mechanical properties of structural steel which had an influence in England on the proportioning of structural steel. He pointed out the necessity of using a lower unit stress on bars subject to alternating strains and called the attention of England to the standards of safety observed by the German Government and American engineers which was 60 per cent higher than that demanded by the British Board of Trade.

The firm, composed of Sir John Fowler and Sir Benjamin Baker, was sought for advice upon the important engineering projects of the time and all the early tube railways had the benefit of their services. They were the engineers for the Central London Railway, where they carried out their design of locating the station on the summit of an incline. with the result that a reasonably high speed for a city railway was for the first time obtained.

Sir Benjamin was consulting engineer for the Baker Street and Waterloo Railway and he also designed for the Hudson River tunnel a special form of shield fitted with diaphragms dividing the whole into compartments, each of which could, in case of necessity, be used as a diving bell.

The greatest work accomplished by Sir Benjamin Baker was the Assouan Dam on the Nile. The proposal of its construction met with great opposition on account of the danger to the Temples of Philæ. The question was referred to an International Commission of which Sir Benjamin was the English representative. The construction was authorized, Sir Benjamin taking the entire responsibility for the work. Upon its successful completion he was created a Knight Commander of the Bath and was also honored upon this occasion by the Khedive. The latter part of his life was devoted to the study of a system of reinforcements and additions which will enable the reservoir to be doubled. His design was adopted by the Egyptian Government. He advised with the London authorities in regard to the construction of a railway bridge across the Blue Nile into Khartoum, and signed the plans just before his death for a bridge across the Nile at Boulac, the port of Cairo, where the river is 900 feet wide. the main channel 80 feet deep, and the river bed of sand and gravel.

Sir Benjamin was joint engineer with Sir John Wolfe Barry for the Avonmouth Docks, and was engineer for the Walney Bridge, of the Barrow-in-Furness Railway, which is 1100 feet between abutments and has an electrically operated opening span on the Scherzer principle. He was appointed consulting engineer on the West African Railways and served in the same capacity for the Public Works Department of Cape Colony.

At the time of his death he was engaged in widening from 80 to 100 feet the Buccleugh Dock entrance at Barrow and in replacing the swing bridge with one of the roller lift principle. He was also engineer to the Rosslere and Waterford Railway, opening up the new route to the South of Ireland.

Throughout his career Sir Benjamin took a keen interest in the scientific societies associated with his profession. He was a member of the Institution of Civil Engineers; a member of the Council in 1882; vice-president in 1891, and president in 1895. He was president of the Mechanical Science Section of the British Association; fellow of the Royal Society, and at the time of his death was vice-president of that body. He was a member of the Institution of Mechanical Engineers, and served for many years as a member of the Council, being in office at the time of his decease. Up to the last, he took a very active interest in the affairs of the Royal Institution. He was an honorary member of the American Society of Civil Engineers, and honorary degrees were conferred upon him by the Universities of Cambridge and Edinburgh. He was made a Knight of the Order of St. Michael and St. George at the opening of Forth Bridge. He was a member of the Engineering Standards Committee, serving on the Finance Committee, and as chairman of the Sectional Committee on Bridges and Building Construction. The valuable specifications for structural steel issued by the latter Committee are, in large measure, due to him.

His death occurred May 19, 1907 at his residence, Bowden Green, Pangbourne. The remains were interred at Idbury, and memorial services were held at St. Margaret's, Westminster, on the same day.

No. 1183

CHARLES HAYNES HASWELL

In Memoriam

By PROF. FREDERICK R. HUTTON, NEW YORK

Member of the Society

In the death of Mr. Haswell on May 12, 1907, in New York a unique figure has been removed from the stage on which engineering history is being enacted. His position was noteworthy, not only by reason of his age and continued activity, but from the fact that he took part in so many beginnings of the modern era and was preëminent in them.

Horatio Allen ran the first locomotive on this side of the Atlantic when Mr. Haswell was 20 years old; Robert Fulton's first trip of the Clermont took place only two years before his birth. Geo. W. Copeland and B. F. Isherwood were his associates in the design of marine engines: John Ericsson came to the front when he was in the full activity of his work. It was given to him to span the entire history of the introduction of steam into the U. S. Navy, from its beginnings as a modest auxiliary to sail power up to his service as Engineer-in-Chief, and to see the disappearance of power-mast and rigging before the end of his life.

Mr. Haswell was born from English parentage stock in North Moore Street in New York on May 22, 1809. Had he lived ten days longer he would have been 98 years old. As a boy on the docks he saw the early triumphs of the Robert Fulton idea, and remembered the appearance of the Fulton the First, or Demologos, in the waters of New York harbor, and watched her career from her launching in 1814 to her destruction by a magazine explosion in June 1829. This boat was the first steam war vessel in the world.

From 1807 to 1835 a maritime service of over seven hundred vessels had grown up on rivers and lakes, with some coastwise vessels, few of them larger than a modern tug. Mahlan Dickerson, then Secretary of the Navy, approved a recommendation of the Board of Navy Commissioners that a person be secured as "engineer; his services will be much wanted in superintending the construction and arrangement of the engines and boilers" of a vessel then being constructed at the New York navy yard, and in July 1836 Mr. Haswell was appointed, on his application for the place, to the position of chief engineer of the Fulton the Second. This was the first creation of such a position: Mr. Haswell had designed the engines and Chas. W. Copeland[1] the boilers. At this time he was chief engineer of the West Point Foundry Association.

Mr. Haswell had the usual classical education which was the only one possible in his day, and entered in 1828 the works of James P. Allaire. The Allaire Works was a pioneer in the days of New York's engineering supremacy, sharing with the Novelty Iron Works, The Etna Works, Franklin Forge, the Fulton, Morgan, the Quintard and the Delamater Iron Works the opportunities of the rapid marine development of that day. The East River also had extensive ship yards; among them those of Wm. H. Webb, and Henry Steers.

Mr. Haswell became chief draftsman and designer of the Allaire Works and in 1837 was responsible for the first steam launch or steam yacht, which he called the "Sweetheart." He lengthened the gig of the sloop of war Ontario and fitted to it an engine and boiler, converting it into a steam launch.

The engines of the Fulton were double, each 50 by 108 inches, and turning a separate side wheel of 22 feet 9 inches diameter and 11 feet face. These engines were on the spar deck; the cranks and shaft were of cast iron.

In 1839 two naval Boards, one of commodores and the other of constructors, the latter having Mr. Haswell as one of the members, started the construction of two side-wheel steam frigates, the Mississippi and Missouri. Mr. Copeland designed the engines and boilers, in his relation as consulting engineer, with a title of Principal Engineer, for the Board of Navy Commissioners, and Mr. Haswell was detached from the Fulton to work over the details of construction.

It was in connection with these boilers that Mr. Haswell laid out the shape and dimensions of each plate for the first time in history, using the methods of the mould-loft for this purpose. The boilers were of copper as was usual in those days. The Mississippi had two side-lever engines with cylinders 75 by 84 inches; the Missouri had two inclined engines 62½ by 120 inches. The vessels were of wood and were completed in 1842. After serving with Mr. Copeland on

[1]Mr. Copeland was treasurer of The American Society of Mechanical Engineers for many years and later vice-president. On his death he gave the Society an option on the purchase of his library, and much valuable historic literature came to it in this way.

the designs of the Michigan, Mr. Haswell returned to the Missouri, as her chief engineer.

On August 31, 1842, very largely at Mr. Haswell's initiative, was approved the act of Congress, creating a corps of engineers and assistants and providing for a "skillful and scientific engineer-in-chief" and on Oct. 3, 1844 Mr. Haswell was appointed to this post. In 1845 the engineer corps was reorganized under his direction and along lines which remained essentially unaltered until the consolidation with the line of the Navy, in 1899. This was the same year that the Naval Academy was started.

A Mr. Gilbert L. Thompson, a lawyer and business man, appointed in 1842 on the passage of the act creating the position of engineer-in-chief to serve in that capacity, was responsible for an order replacing the vertical 7 foot smoke stack of the Missouri by two flues each of 3 feet 6 inches. One of these was led horizontally under the deck to the wheel-house on each side, and discharged there the products of such combustion as could be secured. The idea was to use the suction of centrifugal action due to the revolving wheel, and to dispose of and conceal the smoke by entangling the carbon with the water raised by the paddle-floats. Not only were the flues too small, but the boilers were abaft of the engines and shaft, compelling the gases to go against the current due to the motion of the vessel. Mr. Haswell, as chief engineer of the ship, protested against the change proposed but was over-ruled; and when the scheme failed most signally, he was made a sort of scape-goat and suspended from duty. In recognition of the injustice, however, his restoration to duty and to the ship was offered to him on condition that he would apologize for his error. He refused the opportunity tendered to him in words which have been often quoted: "I would rather suffer injustice from another than be unjust to myself."

Mr. Haswell on leaving the Navy was at once employed on designs for engines for the U. S. Revenue service, and in December 1843 was called back to be engineer-in-chief of the Navy, and in October of the the next year Mr. Thompson's name was dropped from the list and Mr. Haswell's regular service began. The Missouri was burned in 1843 from the breakage of a carboy of turpentine; and it is to be noted that a request of the year before from Haswell for a lead tank for the turpentine had been refused by the authorities. The Mississippi, her sister-ship, was Commodore Perry's flagship in the expedition to Japan, and was the ship where the incident is said to have occurred emphasizing that "blood is thicker than water" in the Pei-Ho river engagement.

In the early years of Mr. Haswell's service, 1842–1849, he saw the experiments tried with the Hunter scheme of placing the paddle wheels on vertical axes, the idle arc of their circumferences being within the hull surface, so that only the operative arc projected. In 1842 the beginnings were made upon the Stevens Battery; in 1842–1845 the Princeton embodying John Ericsson's screw propeller was ordered and built by the efforts of Captain Richard P. Stockton. This was the first screw steam war vessel and was also the first one to have all machinery under the defensive water line. She was designed for anthracite coal to eliminate the betrayal by smoke; had forced draft from blowers, a telescopic smoke stack, and had Ericsson's vibrating piston engine, with a direct connection to the shaft without the gears which had been advocated by other designers.

It was in 1841–1842 that the design was made by Mr. Copeland of the engines and boilers of the Michigan for use on the Great Lakes service. There were two inclined engines 36 by 96 inches and the hull was of iron, the first iron ship made. When the writer last visited the vessel at Erie, Pa., these engines were still in use and in excellent working order.

In 1846, Mr. Haswell suggested the practice of hanging slabs of zinc in the boilers of vessels using seawater containing hydrochloric acid as a means of neutralizing galvanic action between copper and iron in such acid solution. Such plates were put in the Princeton's boilers and in those of the Legare of the Revenue service. This was nearly thirty years before this plan was tried in England as a new invention, and was kept up in coastwise practice until the use of distilling outfits diminished its significance.

In 1847 a Board of which Mr. Haswell was a member decided upon four vessels: the engines of the Susquehanna, which resulted from their decision, were designed by Mr. Copeland, and those of the Powhatan, by Mr. Haswell. The Susquehanna had inclined engines 70 by 120 inches and 31 foot wheels; the Powhatan's were of the same cylinder volume but had vertical air pumps, and built up wrought iron box-girder frames. The Powhatan had Worthington pumps as auxiliaries, and the first donkey-boiler for port use. The drawings were made by Mr. Haswell's own hands and are noteworthy in that they were built up from details without a previous general assembly drawing.

The two other ships were the Saranac and San Jacinto, the engines of the latter being designed by Mr. Haswell. The Saranac was a paddle wheel boat, the other screw driven. The engines driving the screw were 62½ by 50 inches, placed athwartship, and inclined upward and outward. Back-acting connecting rods transmitted the motion to the crank shaft which lay between the head ends of the cylinders. The boilers were still of copper; the propeller shaft 20 inches to one side of the center line, so as to avoid the stern-post.

Mr. Haswell protested again against some of the limitations imposed upon his design by the Board, and the difficulties so imposed compelled some details which could not be defended on any other grounds. The public controversy resulted in the appointment of a civil engineer of prominence, Charles B. Stuart, to the position of Engineer-in-Chief of the Navy. Mr. Haswell was made chief engineer of the San Jacinto and B. F. Isherwood, who had been with Mr. Stuart on the Erie Canal was detached from the Light-house Board and made technical assistant to the latter. The propriety of assigning Mr. Haswell to the care of engines which he had himself designed, and in whose success he would be keenly interested, dictated this assignment.

Unfortunately Mr. Haswell was then suffering from physical disability brought on by a torpid liver and chronic dyspepsia, and had stated that he ought to resign. He was persuaded to defer action until his arrival in Spain where if he had not improved, he would receive word which would withdraw him on sick-leave. By a double combination of misunderstandings, and resulting inaction by friends of Mr. Haswell and by the Secretary of the Navy, no such relief was awaiting him. He was on the sick list and relieved from duty, but was refused his detachment from the ship; sick, disgusted and depressed, he left the vessel and returned to his own country. This was technically met by official action severing him from the Navy on May 14, 1852. Legislative action was proposed in 1859 to confirm him as a chief engineer and was again brought up in February, 1907, to secure him an honorable discharge. Mr. Haswell took little or no interest in these matters himself.

On returning to New York Mr. Haswell entered civil life and engaged actively in his professional work. He became a member and was President of the Common Council of the City; a trustee of the New York and Brooklyn Bridge which was the first of the series; surveyor of steamers for Lloyd's and the Marine Underwriters of New York, Boston and Philadelphia; consulting engineer for the Health Department, Quarantine Commission, and Department of Public Charities and Correction. He designed and superintended the erection of the long crib at Hart's Island in the harbor and the filling in of Hoffman's Island. He designed and superintended the construction of many commercial vessels, and some heavy foundations for lofty buildings. He was one of the consulting engineers of the Board of Appointment of New York, and at his death left uncompleted the extensive construction and improvement work in progress at Riker's Island. As lately as in 1905–1906 in severest winter weather he used to go down frequently to give this work his personal supervision.

Apart from his earlier service to the U. S. Navy, Mr. Haswell was probably best known by the preceding generation by reason of his "Pocket-Book." It antedated the first Trautwine and Searle's in the civil engineering field and was a treasure house of practical information not to be found in encylopedias and text books of that day. It was the progenitor of the more comprehensive Kent and Suplee of the current period, but the author kept it fresh, and last year it appeared in a seventy-second edition. Over 146 000 copies have been sold during its continuance. Mr. Haswell also wrote "Reminiscences of an Octogenarian," covering old New York from 1816 to 1860.

Recognition came to Mr. Haswell from many directions. In 1853 on a visit to Russia, the Emperor Nicholas gave him a diamond ring. He was an Honorary Member of The American Society of Mechanical Engineers and honorary or life member of many other organizations, such as The Institution of Civil Engineers of Great Britain, The Institute of Naval Architects of Great Britain, The American Society of Civil Engineers, The Society of Naval Architects and Marine Engineers, the Engineers' Club of Philadelphia, the Society of Municipal Engineers of New York, the American Institute of Architects, The New York Academy of Sciences, the New York Microscopical Society, the Society of Authors, The Boston Society of Civil Engineers and others. In 1897 he was a representative and delegate to the International Congress in London from the Society of Naval Architects and Marine Engineers, where his age, his reputation and his charming personality made him easily the most remarkable figure in the gathering, and great attention was paid to him as the Nestor of the profession. He was a member of The Engineers' Club, the American Yacht Club, and was dean and oldest member of the Union Club of New York City. He was singularly interested, for an old man, in the doings of the young people, and sympathetic and concerned in the activities of the old Dutch Reformed Church which he attended regularly. His spare figure, with the pink carnation in the coat lapel, was always to be seen in his place until the increasing disability of his last year broke up the habit.

He was greatly interested in the planning and purposes of the Engineering Building in New York for the uses of the Societies.

It occurred to one of the Building Committee that it would be both worth while and pleasant to have him present at the informal function of the laying of the corner stone by Mr. and Mrs. Carnegie in May 1906. A steam motor car, using superheating and partial condensation in a compound engine was used to convey him from his home and back, and it proved that this was his first motor vehicle ride. It added interest that principles for which he had stood in his earlier days should be embodied in the motor which bore him.

His death followed an accidental fall in the dining room of his own home on May 12, 1907. An interesting photograph, in which Haswell and Melville—the first and then active Engineers in Chief—appear, illustrates the account in the Transactions of the unveiling of the monument to Robert Fulton in Trinity Churchyard.

Later, when Admiral Melville had retired, a photograph of Admiral Rae and Mr. Haswell which has been regarded as very successful was taken in connection with a reception at the Engineers' Club in New York.

No. 1184

CHARLES HARDING LORING

In Memoriam

By WALTER M. McFARLAND
Member of the Society

The death of Admiral Charles Harding Loring (Chief Engineer, U. S. Navy, retired) on February 5, 1907, removes a man who had been a prominent figure in engineering circles and in our Society for many years. He was a member of the Society almost from its organization and had filled its highest offices, being a Vice-President in 1885–1887, and President for the term 1891–1892. However great a man's professional ability, his free election to such high offices is a strong testimonial to his worth as a man, and is, indeed, the highest tribute of the personal regard in which he is held by his fellow-members. As will appear in this brief sketch of his life and work, he had filled all the highest offices to which a man in his branch of engineering could aspire, and he had been privileged to take a very active part in furthering the progress of marine engineering.

He was born in Boston, December 26, 1828, and received his education in the public schools of that city. As his educational period was before the day of technical schools, he followed the usual course of preparation for mechanical engineering and served a regular apprenticeship in the machine shop. At its close, in 1851, he entered the navy as a third assistant engineer, attaining, by competitive examination, the highest place in a class of fourteen.

His entrance was just too late to give him an opportunity for participation in the Mexican War, and by the time the Civil War broke out he had passed through all the junior grades and had become a chief engineer. During his service in junior grades he had been laying the foundation for his more important work when an older man and in higher positions, a portion of his shore duty having been as assistant to the engineer-in-chief of the navy, Mr. Samuel Archbold, in which capacity he had charge of the experimental work and tests of engineering devices coming before that office. It is interesting to note that while engaged in this duty he made a test of the first injector which came to this country.

During the Civil War he was in active service the whole time and during the last eighteen months was fleet engineer of the North Atlantic Station, being attached to the fine old steamer Minnesota. He was on board this ship during the attacks of the Merrimac on the Northern fleet in Hampton Roads on the eighth and ninth of March, 1862, when the Cumberland was sunk and the Congress burned and when the Minnesota also was attacked.

A little later he was detached from sea duty and sent to Cincinnati to supervise the construction of three river and harbor monitors and also of some light-draft sea monitors building there. Subsequently he was made general inspector of all the iron-clad steamers building west of the Alleghanies, having in charge at one time eleven monitors building at Pittsburg, Cincinnati and St. Louis.

During the Civil War a number of excellent engines had been accumulated for hulls which were in process of construction, but with the close of the war all work was stopped, and after a time a board was appointed to recommend the best disposition of these engines which were stored in the various navy yards. It was about this time that the compound engine was coming into general use, and the same board was directed to make a study of the compound engine, with a view to its introduction in naval vessels. Of this board Admiral Loring was senior member, and associated with him was the late Chief Engineer, Charles H. Baker.

After a very exhaustive study of the subject, they recommended the introduction of compound engines and the abandonment of the simple form, and the conversion of a number of the engines which were on hand into compound engines. Four sets of these simple engines were so converted and were fitted to the Vandalia, Marion, Quinnebaug, and Swatara. The tests of these engines were very satisfactory and showed a coal economy for short runs of not much over two pounds of coal per horse-power hour.

This study of the compound engine made it natural that Admiral Loring should be selected as the representative of the Navy Department when, in 1874, he and the late Dr. Charles E. Emery made an elaborate series of trials of the engines of the revenue cutters Rush, Dexter, Dallas, and Gallatin, to determine by actual test the relative economies of compound and simple engines, designed for the same work in similar hulls, and also to secure reliable and authoritative data with respect to the economy of steam jacketing. These tests were the first of the kind conducted under circumstances of entire reliability, with the result that the report of the trials was republished all over the world and is still quoted in all the textbooks on steam engineering.

Admiral Loring's next tour of sea duty was as fleet engineer of the Asiatic Station on the U. S. S. Tennessee, where he had as his chief assistant, George W. Melville, who later became his successor as chief of the Bureau of Steam Engineering. There was nothing specially eventful in this cruise, and at its end, in 1880, he was assigned as the head of the steam engineering department of the New York Navy Yard.

This was the period of greatest inactivity in the history of the navy, and there was little to do, even for a very active man, except routine work. During this tour, however, Admiral Loring was senior member of a board which made a test of the machinery of the Anthracite, a little yacht with a triple expansion engine working with 600 pounds pressure. The experiments were valuable as showing that, with the form of apparatus on board the Anthracite, there was no such gain in economy as to warrant the tremendous pressure carried, while it involved numerous practical difficulties.

In 1881 he was a member of what is known as the First Naval Advisory Board, appointed by Secretary Hunt to formulate a shipbuilding program for the navy which he might submit to Congress. The personnel of this advisory board was distinguished in all its branches, and the work they did made possible our splendid fleet of today, as they definitely decided, against strong professional opposition, to abandon wooden hulls for those of iron and steel, and for general progress in every respect. In 1882 he was a member of another important board known as the Navy Yard Board, of which Admiral Luce was senior member. The duty of this board was to visit all the navy yards of the country for the purpose of determining which of them might with advantage and economy be closed. It was a delicate task, but the report, when finally approved, gave general satisfaction, and its recommendations were carried out.

On the retirement of Engineer-in-Chief Shock, only two successors were thought of, one of whom was Admiral Loring, and his merit and thorough qualification for the position were so well recognized that the appointment came to him entirely unsought. This was in 1884, during the administration of President Arthur. Secretary Chandler was presiding over the Navy Department at this time and it was under his supervision that the four vessels, commonly known as the Roach cruisers, the Atlanta, Boston, Chicago, and Dolphin, were built.

Part of the scheme of the building of the new navy was the organisation of what was known as an Advisory Board, composed of two civilians and a number of naval officers. Owing to this regime the bureaus were not given the same free hand that has obtained since the Advisory Board was discontinued, although they did valuable work in the details of designs. Forced draft was used on these new vessels, after having been tried on two others—the Alliance and Swatara—under Admiral Loring's direction.

The change of administration in 1885, when Mr. Whitney came in as Secretary of the Navy, brought additional trouble for Admiral Loring. The Democrats had been so long out of power that they came in prepared to find everything wrong, and there were busybodies to throw out hints and insinuations against Loring. It is probable, too, that he and Whitney were naturally incompatible. Whitney was a nervous pushing man, who wanted everybody around to appear to be hustling. Loring was a man of great dignity with none of the arts of the courtier or politician. Instead of running to Whitney with every detail of his work and thereby becoming, at least, intimately acquainted with him personally, he was content to conduct his work by written reports. He worked just as hard, but Whitney did not appreciate it. The backbiters, who had Whitney's ear (and it is sad to relate that there were naval officers among them), led him to believe that Loring was not abreast of the times or capable of providing the best machinery. Indeed, the attack was upon the whole Engineer Corps, and it is a fact that negotiations had been conducted with a prominent British engineer to come over and do our designing for us. This was only prevented by the law officers pointing out that it violated the contract labor law.

It may be mentioned in this connection that the Anglophiles persuaded the Secretary to buy a number of plans abroad. They were not purchased by experts, with the result that we were undoubtedly "done" in the transaction. It would have been a safer thing to purchase complete ships, which would, at least, have had to make successful trials. The history of the Texas is too well known to engineers to need repetition here.

The result of all these conditions was to convince Loring that he did not have Whitney's confidence and that for the sake of his corps, he had better give up his office as engineer-in-chief. Accordingly, in 1887, he tendered his resignation.

After leaving the Bureau of Steam Engineering he was made senior member of the Experimental Board of Naval Officers at the New York Navy Yard, which board, under his direction, conducted many exceedingly valuable experiments. Among the most important were the competitive tests in 1889 of water-tube boilers to determine the type that should be used on the coast defence vessel Monterey, and it may be well here to call attention to the fact that this was the first case on record where a boiler had ever been run continuously for twenty-four hours when burning more than fifty pounds of coal per hour per square foot of grate.

Another very important series of experiments conducted by Admiral Loring were those on the boilers of the torpedo-boat Cushing, to determine the economy of evaporation with different air pressures and rates of combustion. These experiments have proved of the greatest interest, and form a very valuable collection of engineering data. A number of clever devices had to be schemed out to carry on these tests, and the whole success was a great credit to Admiral Loring and the board.

Having reached the age limit in December, 1890, he was placed on the retired list; but having always been a man of very vigorous physique, he did not give up active employment and was for a time consulting engineer to the United States and Brazil Mail Steamship Company. During the late war with Spain he was recalled to active duty and assigned inspector of engineering work in New York.

Admiral Loring was a man of great personal attractiveness and to most of his friends the social side of his character was the more important. They admired the able engineer, but they loved the man. Although a man of great dignity, as has been mentioned, this only repressed undue familiarity, and he was a delightful companion. His keen sense of humor and remarkable skill as a *raconteur* made him a decided acquisition to any company. It was remarked by a brother officer, himself remarkable for his abilities as an entertainer, that Loring was the best "diner out" in the Navy. He wrote well and was a good speaker, doing these with the dignity and elegance which were a part of his nature.

He was President of The Engineers' Club for two years, thus receiving the highest social honor which engineers can confer. His incumbency of the Presidency of our own Society has already been mentioned. He was also a Vice-President of the Society of Naval Architects and Marine Engineers from its organization until his death, and while his health permitted was very active in its council and general meetings. The Army and Navy Club of New York owed much to his active interest, as he had filled most of the offices and was, for a number of years, its Secretary. He was also a member of the Loyal Legion and of the Grand Army of the Republic.

He had grown old gracefully and slowly, so that, although in his seventy-ninth year when he died, he did not look much over sixty. In appearance, there was quite a resemblance to President Cleveland but as they differed very radically in politics, Admiral Loring did not count this as a special privilege.

In reviewing this life, we are struck with the relatively brief period during which marine engineering has been a practical success. Although his life did not, like that of our beloved Uncle Charley Haswell, cover the whole period, yet Admiral Loring was in personal touch with all the steps of progress, going back to box-boilers and side wheel engines and coming down to water-tube boilers, forced draft, triple expansion engines, and the steam turbine. In nearly all of these he had an active and sometimes an important part, so that he could justly feel that he had not only done his duty but had been a factor in the advancement of the profession and the service he loved so well.

No. 1185

COLEMAN SELLERS

IN MEMORIAM

By H. F. J. PORTER

Member of the Society

Coleman Sellers, Sc.D., E.D., died at his residence, 3301 Baring Street, Philadelphia, on Saturday evening, December 28, 1907, and was interred at West Laurel Hill Cemetery on Tuesday, December 31. The funeral services were attended by a large number of personal friends and associates, including prominent representatives of the Board of Directors and of the operating organization of the Niagara Falls Power Company, many old employees of Wm. Sellers & Co., Incorporated, and others associated with him in his many activities.

MEMORIAL

Coleman Sellers the youngest son of Coleman and Sophonisba (Peale) Sellers, was born in Philadelphia, January 28, 1827. His father was a man of broad culture and influence, an ingenious mechanical engineer and a manufacturer of considerable reputation in his day. His grandfather and great-grandfather had been well known engineers, who served in turn on important commissions connected with public road and canal improvements, and each of his progenitors since the family came to Pennsylvania in 1682 had evinced marked mechanical and inventive ability and a taste for scientific pursuits.

His maternal grandfather was Charles Wilson Peale, the portrait painter, naturalist and versatile genius, distinguished for his diversified knowledge and untiring activities.

In fact if there is any foundation for the theory that heredity plays a part in shaping one's proclivities, it might be said that the preparation of his career commenced in the generations that preceded him.

He was but five years old when his father died and his instruction thereafter devolved upon his mother. This was supplemented by a system of manual kindergarten devised for him, in the belief, as his parents had been taught, that the training of the hand as well as of the mind has an important influence upon the all around development of the individual.

Later he attended private schools in Philadelphia and finally at the age of eleven entered Bolmar's Academy at West Chester, conducted by Anthony Bolmar, a Frenchman and former officer under Napoleon, who made his school famous by his personal influence, high sense of justice and honor and his rigid discipline.

His interest in the solution of physical problems was stimulated by the elementary lectures in natural philosophy, which were given to the students by the local talent available, but the indefinite character of information derived from this source and the lack of good text books on scientific subjects aroused his natural curiosity to know more accurately the causes for certain effects. Thus we find him devoting much of his spare time to making apparatus to demonstrate practically the theories imperfectly enunciated in the classroom, and this trend of his mind is indicated by the entries in his diary, which he was then methodically keeping. Methods thus instituted by frequent repetition became habits which characterized his life work, and whenever any new discovery in the world of science or industry was announced, it came naturally to him to investigate it fully, and very often, in his thorough mastery of the subject, he improved upon the previous method or product.

He completed the course at Bolmar's Academy in his seventeenth year, and acceding to his mother's wishes, began to devote himself to practical agriculture on the farm of one of his kinsmen. Here his natural proclivity to put into service his mechanical bent wherever applicable asserted itself in attempts to improve the implements he found on the farm and among other devices he designed a metal toothed hay rake mounted on wheels, which anticipated by many years the machine later re-invented and now generally in use.

After two years of this service his brothers, who were operating the Globe Rolling Mill in Cincinnati, Ohio, responded to his desire for an opportunity to enter the mechanical field by offering him employment.

With his customary assiduity he applied himself to acquiring a knowledge of the details of the mills and processes incident to the rolling of wire rods, merchant iron and flat rails, as used at that time on the railroads of the West. The wire mill connected with the establishment was overhauled and improved under his direction and while engaged in making wire for O'Reilly, then known as the Telegraph King of the West, he procured from him a few cells of the battery used in the telegraph outfits of the day and repeated the experiments announced in the press as having been performed by Faraday and others, making all the necessary apparatus with neatness and precision.

During his stay in Cincinnati, young Sellers, on account of his prompt and thorough investigations of discoveries as they were announced, became the mentor of a coterie of intellectual men who looked to him to elucidate the subjects under consideration and thus he was frequently called upon to entertain his friends by carefully prepared lectures illustrated by practical experiments involving chemistry, electricity and physics. He became an active member of the Mechanics' Institute and read many papers on pertinent subjects before its meetings.

He soon became Superintendent of the Globe Iron Works, and during 1850–1851 undertook the building of locomotives of their own design for the Panama Railroad. It was at this time that he married Cornelia Wells, daughter of Horace Wells of Cincinnati, one of the pioneer type founders of the West, and thus began a life-long union of mutual devotion and sustained happiness.

Upon the completion of the Panama Railroad engines he was induced to enter the service of James and Jonathan Niles in charge of their locomotive works in Cincinnati, and remained there until 1856 when on the solicitation of his kinsmen, William Sellers & Co., he accepted the position of chief engineer in their works at Philadelphia.

He remained with this firm for over thirty years, being admitted to partnership in 1873. During this time he designed a great variety of machinery, covering not only all the usual machine tools, but a large number of special machines for various purposes, all of which were characterized by originality of conception, the application of correct mechanical principles and that simplicity and elegance of design which has since been followed by builders of machinery the world over. His capacity of invention is attested by the long list of patents which bear his name, either alone or associated with others, and through his initiative the modern system of transmission of power by shafting was established.

While actively engaged in the arduous duties of chief engineer of this large and growing concern, Mr. Sellers still found time for much work of scientific character often suggested by questions that arose in his business and by matters of public concern. In 1858, when the new art of photography began to supplant the ambrotypes and daguerreotypes of the day, Mr. Sellers at once became interested in it, primarily to make its use applicable for the illustration of machinery for advertising purposes. He quickly learned the art, and not only acquired considerable skill as an amateur, but in the course of this diversion he invented valuable improvements in processes and apparatus. During 1861–1862 he acted as American correspondent for the British Journal of Photography and was for many years a frequent contributor to American photographic publications. He was one of the founders of the Philadelphia Photographic Society and a prominent member of the Amateur Exchange Club. In 1861 he made and patented a device which he called the kinematoscope, which was a forerunner of the present moving picture machine. The machine accomplished its object in a practical manner, showing pictures of objects in motion, and it only required for its full development instantaneous photography for which at that time sufficiently rapid plates were not available.

For the accomplishment of the requirements which his scientific research demanded, he fitted up a work room in his home, equipped it with complete wood and metal working machinery and laboratory apparatus for chemical and physical and microscopic investigation and a photographic dark room.

He was thus prepared for original investigation when questions arose in his professional work which demanded solution, .and it became his habit to devote to study and research those hours which are usually given to rest and recreation.

Thus it once occurred to him that valuable information might be obtained by a careful microscopic study of the stony deposit or scale, which forms in steam boilers when certain waters are used, and, entering into the investigation with his usual zeal, he prepared a number of interesting specimens by mounting sections which he ground to a transparent thinness for study with polarized light. He familiarized himself in this way with the methods of mounting microscopic specimens both wet and dry, and prepared a number of excellent slides, incidentally devoting particular attention to the diatomaceous earths and fresh water algæ. He also contrived a number of handy appliances for use in connection with this work, and later, as a matter of amusement, applied the microscope to lantern work, providing himself with an oxy-hydrogen outfit, and making his own oxygen, as this gas was not then an article of commerce.

He took up the art of telegraphic signaling as a convenience in communicating between the several departments in the extensive establishment of William Sellers & Co., and in the course of a few months he made himself an expert operator, not only signaling, but reading messages by ear, though the average time for the acquisition of this skill is about two years. It was the same with shorthand, which, becoming interested, he quickly acquired, although his opportunities for practice were only the occasional leisure moments of his busy life. Similarly he secured one of the first typewriting machines and thereafter generally used this means of writing all his papers and correspondence.

He served with Dr. Horace Howard Furness and others as a member of the commission appointed by the University of Pennsylvania, in accordance with the bequest of the late Henry Seybert, to investigate the phenomena of modern spiritualism. These researches were begun in 1884, and continued for three years, during which time Dr. Sellers' experience was of great value to his associates in devising tests and suggesting methods of investigation and observation. His strong common sense, his thorough knowledge of natural laws, predisposed him at all times to challenge those who claimed occult powers, and enabled him to detect the impostures of charlatans. While he was entirely untrammeled by prejudice and his mind was ever open to the reception of new truths, he never was inclined to credit to supernatural agencies phenomena the occurrence of which could be explained by the operation of those forces of nature which are already recognized.

After his return to Philadelphia in 1856 he identified himself with the Franklin Institute, serving on numerous important investigating committees, and contributing largely to the interest of the meetings by timely papers, discussion and lectures. He served as vice-president for several years, and was elected president for five successive terms. He served on the board of managers over a long period and was one of the publication committee that edited the Institute's Journal. He was a member of the American Society for the Prevention of Cruelty to Animals and through his influence his friend and associate, Mr. Lippincott, established a Veterinary School at the University of Pennsylvania.

He was a Charter Member, and a Past President of this Society and the very first technical paper presented at its first meeting in 1880 was by him, entitled "The Metric System: Is it Wise to Introduce it into our Machine Shops?" The argument in this paper was based on intimate experience gained by having personally introduced metric measurements in that part of the shops of William Sellers & Co. where locomotive injectors were manufactured. His well known antagonism to all attempts to enforce the use of the metric system by legislative enactment induced him to write freely on the subject in the technical and newspaper press, and he also prepared, in connection with the late Dr. William P. Tathan, the adverse report which was adopted by the Franklin Institute in 1876.

During the Centennial Exhibition in 1876 he served as one of the special judges for final settlement of difficult or disputed questions of award. For his well-known scientific attainments he was decorated by King Oscar of Norway and Sweden with the order of St. Olaf, and in 1899 the University of Pennsylvania conferred on him the honorary degree of Doctor of Science.

Among the Societies to which Dr. Sellers belonged may be mentioned The American Society of Civil Engineers, The Society of Naval Architects and Marine Engineers, The British Institution of Mechanical Engineers, The Geneva Society of Arts, The Pennsylvania Academy of Natural Science and The American Philosophical Society. His membership in the great British engineering societies was, without solicitation, tendered him in 1884 on the nomination of a number of the most eminent men of science in England.

Dr. Sellers paid his first visit to Europe in 1884, when, as member of the board of managers of the Franklin Institute, he acted as delegate from that society to the ter-centenary of the University of Edinburgh. During a stay of several months in England he visited the large works of Sir William Armstrong and Sir Joseph Whitworth under the most favorable auspices, finding open to him also the doors of any establishment he wished to see, even those that were noted as being generally closed to all the world. In many of these he found some of his own inventions, and that designs made by him as engineer for William Sellers & Co. had been copied and were in use. His trip was extended through France, Germany, Sweden and Norway, in which last mentioned countries he met with a particularly hearty welcome.

In 1886, after a serious illness, he was unable to resume his former duties and accordingly resigned his position as engineer of William Sellers & Co., being succeeded by his son, Coleman Sellers, Jr., who on the death of William Sellers became president of the company. Subsequently he was induced to enter active practice as a consulting engineer, for which work his long practical and varied experience especially equipped him.

His knowledge of the fundamental principles of physics and mechanics was such that they might be compared to the alphabet of a language with which he could correctly spell any mechanical device he desired to construct. With this acquirement was associated his remarkable memory of what had been already attempted or accomplished in the mechanical field, enabling him to recall past inventions and to point out old ideas which from time to time were being resuscitated.

About the time he was established in his practice as consulting engineer, Dr. Henry Morton, President of Stevens Institute, induced him to lecture before the senior class of that institution. This resulted in the establishment of a Chair of Engineering Practice, with Dr. Sellers as a non-resident member of the faculty, and his lectures delivered at intervals during a number of years, were attended, not only by the senior class, but also by members of the faculty, who received from Dr. Sellers' extended experience many hints to aid them in their instruction. In 1887 he received from Stevens Institute the honorary degree of Doctor of Engineering.

In 1889 Dr. Sellers was requested by Mr. Edward D. Adams, the well-known financier of New York, to report on the practicability of developing the available water power of Niagara Falls and its transmission from Niagara Falls to Buffalo, in the interest of what afterward developed into the Niagara Falls Power Company. The proposed utilization of the power of the falls was based upon a scheme that had been suggested by Thomas Evershed, an engineer upon the Erie Canal, who had conceived the idea of placing turbine wheels in a district more than a mile above the falls, discharging into an outlet tunnel that should inconspicuously debouch at the river edge below the falls. Legislation had been obtained upon this scheme from the State of New York, though capitalists were not immediately ready to believe that the project would be commercially profitable. Dr. Sellers' report, however, so clearly indicated the practicability of the scheme that capitalists were readily found who were willing to undertake the enterprise.

He was made consulting engineer of the Cataract Construction Company, a corporation formed to execute the work, and in June of 1890 assisted in the establishment in London of the International Niagara Commission, with power to award $22 000 in prizes for plans or the generation of power by water and its transmission to a distance by the most economic method, regardless of the medium of transmission. This commission consisted of the late Lord Kelvin, then Sir William Thompson, as chairman, with Dr. Coleman Sellers. Lieutenant-Colonel Theodore Turretini, of Geneva, Switzerland (originator and engineer of the great water power installation on the Rhone), and Prof. E. Mascart, of the College of France, as members, and with Prof. William Cawthorne Unwin, Dean of the Central Institute of the Guilds of the City of London, as secretary.

At that time great advance had been made in the transmission of power by wire rope and by compressed air, but very little had been done in the utilization of electricity for power purposes. Inquiries and examination into the best methods of developing and transmitting power then known in England, France, Switzerland, and Italy were made personally by the officers and engineers of the company, and competitive plans were received from twenty carefully selected engineers, designers, manufacturers and users of power in Great Britain, on the Continent of Europe and in America. All of these plans were submitted to the commission in London on or before January 1, 1891, and prizes were awarded for such of the plans as were considered favorably by the commission.

The engineers who were engaged to carry out the plans of the company were organized into a board of which Dr. Sellers was made chairman. The work was begun on the construction of the tunnel, and also on the entrance canal by which the water was to be brought to the turbines. In 1893, when the tunnel was nearly completed and the time for the installation of the machinery was near at hand, the object of the board of engineers had been accomplished, and it was dissolved. It then became preëminently the task of the mechanical engineer to consider and apply the devices best adapted to so control and utilize the forces as to secure the best engineering and commercial results. Dr. Sellers was accordingly made chief engineer of the Cataract Construction Company, and while its separate organization was called for, he served also as president of the Niagara Falls Power Company. It thus devolved upon him to suggest and devise the various details of the installation at a time when its principal features were essentially experimental, and it was his wise forethought and breadth of view in dealing with the new problems that guided the enterprise safely through the complex questions that surrounded it.

Radical changes in the plans were necessary when it became evident that the proper course lay in the abandonment of Mr. Evershed's scheme of a system of distributing canals leading to factory sites where independent water wheels would be installed, and to substitute in place thereof a central power station where the generation of 50 000 horse power would be concentrated for electric transmission to consumers located on the neighboring lands or at a distance. The first three turbines were put in operation in 1895 with a sufficient demand for power in excess of their output to warrant the installation of five additional units, which were shortly followed by two more, making in all an equipment of 50 000 horse power capacity.

The mechanical features proposed by him, including his patented design of the large dynamos and their appurtenances, largely contributed to the success of the initial installation, and have certainly greatly simplified the further extension of the plant, and this work may be justly considered the crowning achievement of his life.[1]

In taking up the practice of consulting engineer, Dr. Sellers had associated with him one of his sons, Horace Wells Sellers, and subsequently admitted to the partnership, Mr. S. Howard Rippey (a member of this Society who was his principal assistant in the Niagara work), under the firm title of Sellers and Rippey.

In the death of Dr. Sellers the scientific world loses a tireless investigator, the mechanical field a prolific inventor, and the host of admirers he leaves behind feel keenly the loss of a deep, personal friendship.

[1] The account of Dr. Sellers' connection with the Niagara Falls project has been derived from the able biography by the late Dr. Henry Morton in Cassier's Magazine of August, 1903, the essential data of which were furnished to him by Dr. Sellers himself.

No. 1186

NECROLOGY

PETER H. BEEN

Peter Hamilton Been was born in Milwaukee, Wisconsin in 1882. He received his preliminary education in the public schools of Milwaukee, and entered the drafting room of the E. P. Allis Company in June 1898. In 1902 he entered the shop of the Milwaukee Machine Tool Company and at the end of a year returned to the Allis-Chalmers Company where he was made assistant chief draftsman, holding that position until his death in 1907. He was interested in the technical education for apprentices and gave much time to this work.

STORM BULL

Storm Bull, professor of steam engineering in the University of Wisconsin, Madison, Wis., died November 17, 1907. Professor Bull was born at Bergen, Norway, October 20, 1856, and was graduated from the Federal Swiss Polytechnic Institute at Zurich in 1877 with the degree of mechanical engineer. He came to this country and in 1879 became instructor in mechanical engineering at the University of Wisconsin. In 1884 he became assistant professor, and in 1886 was made professor. He held this position until 1890, when he was appointed professor of steam engineering.

Professor Bull was a member of the Western Society of Engineers, in which he won the Chanute medal of 1903; the Society for the Promotion of Engineering Education of which he was vice-president in 1901–1902, and the Western Railway Club. Member and vice-president jury of awards, Class 21 of group 4, Paris Exposition, 1900. Member and acting president, jury of awards, Department of Machinery Louisiana Purchase Exposition, 1904. Member American Association for the Advancement of Science, consulting engineer for Wisconsin State Capitol Commission and Board of Regents, University of Wisconsin and others. He was the author of many scientific papers and reviews of engineering text books.

JAMES BLAKE CAHOON

James Blake Cahoon was born at Lyndon, Vt., in 1856. He was educated in the Portland, Maine, Schools, and in the U. S. Naval

Academy, graduating in 1879. He was also a graduate of the U. S. Torpedo School, Newport, R. I., and took special courses in electricity and the manufacture of torpedoes and high speed engines. On account of an injury received while making tests of arc lamps, he was placed on the retired list with the rank of Ensign.

Mr. Cahoon became associated with the Robinson-Foster Electric Motor Company, Boston, as chief electrical engineer, and in 1899 was managing director with the Boston Chemical Company. His next engagement was with the Thomson-Houston Electric Company as electrical engineer, later becoming manager of the special production department. In 1893 he went to Schenectady as head of the expert department of the General Electric Company, leaving there a year later to take up the management of the Elmira Railway and Electric Light Company. In 1899 he assumed the management of the Underground Electric Light Company at Syracuse, N. Y., and in 1901 associated himself with the banking house of Emerson McMillen and Company of New York, and later with Furson, Leach and Company, leaving this business to establish himself as consulting engineer. In 1905 he was connected with the Eldenbel Construction Company, and was made vice-president and chief engineer. He was past president of the National Electric Light Association, and was a member of several engineering societies. Mr. Cahoon became a member of this Society in 1892. He died February 17, 1907.

WILLIAM H. DERBYSHIRE

William H. Derbyshire was born in Canton, Ill., in March, 1859, and graduated from The Polytechnic College of Pennsylvania in June, 1877. In August of the same year he accepted a position with John Roach & Son, Shipbuilding and Engine Works, Chester, Pa. In 1879 he became associated with The Miles Machine Tool Works, remaining with them until their consolidation with Wm. B. Bement & Son, forming the firm of Bement, Miles & Co. With the new company he was made general superintendent, and remained with them in this capacity until November, 1897, when he formed the Chambersburg Engineering Company, Chambersburg, Pa., of which he was president until his death.

Mr. Derbyshire made a specialty of smith shop and boiler equipment and secured several patents on hydraulic equipment, one of the best known of which is the system of quick acting hydraulic riveters and presses. He became a member of the Society in 1890, and died April 13, 1907.

GEORGE HENRY EVANS

George Henry Evans was born in Hull, Yorkshire, England, in July, 1866. He was educated in the ordinary home schools and private colleges and also studied engineering with his father, who was a civil engineer in Norwich, England. In 1890 he was sent out to New Zealand as general manager and resident engineer of the Round Hill Syndicate Mines, at Riverton, New Zealand. While there he had entire charge of all preparatory work in constructing canals, breakwater, and all mining operations. Later he was the manager and resident engineer of the Consolidated Gold Mines of California, Ltd., Mugalia Consolidated, Ltd., Golden Gate of California, Ltd., Morris Ravine Gold Mines, Ltd., Golden Feather, Ltd., The Development Syndicate, Ltd., and as consulting engineer with the Risdon Iron Works.

Mr. Evans' specialty was placer mining, and he was the inventor of the Evans hydraulic elevator, now generally used in the elevation of gravel.

He was a member of the North of England Society of Mining and Mechanical Engineers, the American Institute of Mining Engineers, The Technical Society of the Pacific Coast, and Franklin Institute. He was also a member of the Bohemian Club of San Francisco. Mr. Evans died at Berkeley, California, February 4, 1907.

EDWARD FRANCIS GAVAGAN

Edward Francis Gavagan was born in Boston, Massachusetts in 1878. He received his early training in engineering and electricity in the Massachusetts training ship Enterprise, and spent three years as assistant engineer on the American line steamer St. Paul. He was chief machinist of the United States Navy during the Spanish War and was for a time connected with the Edison Electric Illuminating Company of Boston. He was first assistant engineer, rope walk power plant, United States Navy Yard, Boston, and for one year served as a mechanical engineer detailed to the Philippine Islands, in the United States Civil Service. For three years he was mechanical engineer and traveling representative for the Parson Manufacturing Company, with which he was connected at the time of his death.

Mr. Gavagan was a Junior member of the Society, joining in 1906.

ABEL G. GOLDTHWAIT

Abel G. Goldthwait was born April 17, 1837, at Sandgate, Vermont. He received a common school education and served a four years apprenticeship in mill work in the shops of a Mr. Buck of East Arlington, Vermont, after which he remained several years working in the machine and pattern shops.

About 1861 he was engaged in the mowing machine work in Troy, New York, and two years later was employed by Mr. William H. Tolhurst as pattern maker, but was soon promoted to the drafting and designing departments, later was made superintendent of construction, and when the business was incorporated, he was elected vice-president. He was also its mechanical head.

While in this company he assisted Mr. Hartshorn in designing the Hartshorn window shade roller; he was designer for Mr. H. Stanley in making the first successful paper bag machine which took the paper in a roll and turned out bags, cut, folded, and pasted ready for use; he was principal designer of the Magee hot air furnace; he assisted in designing and constructing some of the first double-plate rim-braced, cast iron car wheels; he designed a saddle tree, the parts of which were made so as to be interchangeable, and orders for them from the Government amounted to 80 000; he was the designer of many of the paper box machines now in use; he successfully modified Mr. Holley's design of the converter for the Bessemer steel process; he designed most of the machinery used in the manufacture of paper collars in Troy, and drew the plans and superintended the construction of laundry machines for ironing both sides of a linen collar at one operation, and other laundry machines, among which was the Tolhurst Hydro-Extractor, which made possible the use of very large extractors with a miminum of vibration.

The first successful design of the universal car coupler, now used on all railroads in the United States was made by Mr. Goldthwait. He made many valuable improvements in the construction of magnetic ore separators, designing many valuable new features.

Mr. Goldthwait was elected a Member of the Society in 1892. He died November 17, 1907.

EUGENE GRIFFIN

Eugene Griffin was born in Ellsworth, Me., October 13, 1855, and was educated in the public schools of that place until he entered the United States Military Academy at West Point, from which institution he was graduated in 1875, standing third in his class.

Immediately following his graduation, he was appointed Second Lieutenant of Engineers in the United States Army, and was assigned to duty at the Engineering School of Application at Willet's Point, where he remained until 1877. During the years 1878–1880 he was in charge of a party of engineers in the United States Geographical Survey in Colorado, New Mexico, Arizona, and Texas. He was promoted to First Lieutenant in 1880 and was in charge of surveys of Governors, Ellis and Bedloe Islands in New York harbor.

From 1883 to 1885, he was Assistant Professor of Civil and Military Engineering and the Art of War at West Point. In 1885 and 1886 he was aide-de-camp to Gen. Winfield Scott Hancock. From 1886 to 1888 he was Assistant Engineer Commissioner of the District of Columbia, having charge of all matters pertaining to electric lighting, telegraph and telephone companies in the city of Washington. In 1887 he was promoted to Captain in the Corps of Engineers, and early in the year 1888 entered the employ of the Thomson-Houston Company to organize and manage its Railway Department, then just being formed.

In 1892 the General Electric Company was organized and absorbed the Thomson-Houston and Edison General Electric Companies. Captain Griffin was elected Director and First Vice President of the new company, and held these official positions at the time of his death.

Upon the declaration of war with Spain in 1898 he was commissioned by President McKinley to organize the First Regiment of Volunteer Engineers. He was promoted to the rank of Brigadier General prior to his regiment being mustered out of service, and at the close of the war he resumed his active duties with the General Electric Company.

He was a member of the Union, University, and the Army and Navy Clubs, and one of the Board of Trustees of The Engineers' Club. He was a member of The American Society of Civil Engineers, The American Institute of Electrical Engineers, and became a member of this Society in 1889.

General Griffin was buried at West Point with military honors on Saturday, April 13.

ALBERT F. HALL

Albert F. Hall was born in Somerville, Mass., December 6, 1845. After attending school in Charlestown he entered the first class ever formed at the Massachusetts Institute of Technology. He was the only mechanical engineer in the class which was graduated in 1868. After graduation he entered the employment of the George F. Blake Manufacturing Company, remaining with them forty years, until his death. During this time he invented and designed some of the largest pumps in use in this country, among which are the twenty million gallon triple expansion pumping engines built for the new high service stations of the New York City Water Works.

He was one of the first to advance the idea of heat unit system as the basis to compute the efficiency of the steam engine, and in 1894 he presented before the Society a paper on this subject at the meeting at Montreal. He also contributed many other engineering articles for publication, one of his latest works being on the development of the theory and the practical application of the centrifugal pump.

He made many valuable improvements in the direct acting steam pump, taking out numerous patents. The valve-gear known as the "simplex" was one of his latest inventions. In collaboration with others, he developed the vertical twin air pump and the vertical double-acting suction valveless air pump.

Mr. Hall died at Somerville, Mass., on July 22, 1907.

CHARLES J. HILLARD

Charles J. Hillard was born December 5, 1846 in New York. He received his education in New Orleans, and coming North in 1862, was apprenticed as machinist at the Morgan Iron Works serving in the machine shop and the drafting room. He was afterward draftsman for A. S. Cameron and Company, New York; chief draftsman, Knapp Fort Pitt Foundry Company, Pittsburg; he was two years manager for John J. Endres, mining engineer and manufacturer, of Pittsburg; from 1873–1876 he was engineer of the Atlas Works Company, Pittsburg; and founded and operated the firm of Hillard. Sterrett and Company, Ltd., 1876–1885.

Mr. Hillard was also secretary of the Sterling Steel Company; manager, Bois and Gazzam, Limited; chairman and resident manager Centre Mining Company, and at one time held a directorship in the Diamond National Bank of Pittsburg.

Mr. Hillard died September 12, 1907.

EDWARD WARREN JOHNSON

Edward Warren Johnson, was born November 2, 1860, at Hinsdale, N. Y. He erected two planing mills for the Peuna Lumber Storage Company with a capacity of 150 per day and superintended the running for about three years, from 1888 to 1891. He resigned and patented a planer knife sharpener and file. From 1893, for about two years, he did mechanical work for J. Y. Wilson Manufacturing Company, Olean, New York, after which he was superintendent of lines, connections, pumps and tanks for the Standard Oil Company, constructing and running tar paraffine plant. In 1890 he was transferred to Bayonne, N. J.

Since 1902 he was engaged in the work of master mechanic, designing and constructing a great variety of mechanical works, having directly under supervision a large force of men.

Mr. Johnson met his death through an accident at Bayonne, N. J. November 12, 1907.

WILLIAM SAMUEL LOVE

William Samuel Love was born in St. Louis, Mo., May 20, 1867. He received his early education at Smith Academy and the Manual Training School of St. Louis, graduating from the latter institution with the class of 1883. For a year he was engaged in railroad survey work through Texas, entering Washington University in St. Louis in 1884 and graduating from the mechanical engineering course with the degree of B.S., with the class of 1888.

His practical experience was obtained during his college course in the shops of the St. Louis Bridge and Terminal Railway Company in 1885 and 1886, and in the drawing room of the same company in 1888. He was for a year assistant engineer for the St. Louis Tie Preserving Company, and for three years was Secretary of the Pond Engine Company of St. Louis.

In 1892 he opened an office in Chicago, Ill., as mechanical engineer and agent for various steam engines, boilers, heaters, etc. In 1895 he took charge of the Chicago office of the Abendroth and Root Manufacturing Company of New York and assumed charge of the Chicago office of the Wheeler Condenser and Engineering Company in 1899. He remained in that position until January 1907, at which time he came to New York as general sales manager of that company, which position he held at the time of his death.

Mr. Love was a member of the Western Society of Engineers, The Engineers' Club of New York, Union League Club of Chicago and the Loyal Legion.

He was deeply interested in the development of surface and jet condensers, and during the last ten years of his life, was instrumental in perfecting condensers of large capacity.

Mr. Love died December 11, 1907.

HERBERT CLIFTON MOYER

Herbert Clifton Moyer was born in Danville, Pa., 1873. He graduated from the high school, and at a very early age constructed a miniature steam engine whose novel features attracted public attention. After graduating he entered the employ of the Enterprise Foundry and Machine Works where he served an apprenticeship,

afterward entering the drafting rooms of the mechanical department of the Mahoning Roller Mills Company. He was next employed at the Mount Carmel Iron Works, the South Sharon Steel Company, and the Lukens Iron & Steel Company at Coatesville, Pa., retaining the latter position until his death, November 8, 1907.

WILLIAM ROBERTS

William Roberts was born in Watertown, Massachusetts, March 25, 1835. After attending the Waltham Public Schools and the Auburndale Institute, he was apprenticed in 1851 to the Boston Manufacturing Company, Waltham, Massachusetts, as machinist, for three years, being made a journeyman in 1854. He worked at the Norfolk Navy Yard as journeyman until 1855.

On August 2, 1855, Mr. Roberts was appointed third assistant engineer for the United States Navy. He was with Commodore Perry on his expedition as assistant engineer on his flagship The Niagara, which opened the ports of Japan, and served on the Michigan, on the Lakes in 1856. In 1857 he was promoted to the office of second assistant engineer, served on the steam frigate Roanoke on the coast of Central America, and was one of the officers of the steamer Fulton at the time of the capture of the filibuster Walker in 1858. In July, 1859, he was made first assistant engineer and served on the Memphis on the Paraguay expedition. He resigned in September, 1859, and reënlisted, in response to the call for men, in April, 1861. At the attack on the forts and batteries at Pensacola Bay, in 1861, he was on the frigate Niagara, and in 1862 he was an officer of the steam sloop Housatonic when she drove two iron clad rams into the fort at Charleston.

In 1863, he was promoted to the office of chief engineer and was attached to the frigate Niagara, then undergoing repairs at the Charlestown Navy Yard. He served at sea and at navy yards as chief engineer and performed service at the Navy Department at Washington, until 1869.

In March of that year Mr. Roberts resigned his position in the Navy, and became associated with his father in the manufacture of paper in Waltham. He was also engaged as an expert in steam and hydraulic engineering. Under the firm name of John Roberts and Son, he carried on the paper business until the time of his death. Roofing paper and coarse wrapping paper were the principal products of the mill until the advent of asbestos paper, Mr. Roberts being the first to produce asbestos fireproof paper.

Among the societies of which Mr. Roberts was a member, are The Grand Army of the Republic, and The American Society of Civil Engineers. His death occurred December 28, 1907.

GEORGE ROWLAND

George Rowland was born in Brooklyn, N. Y., December 22, 1865. He attended school at several private institutions, and completed his education at Columbia University, graduating from the School of Mines in the class of 1887 with the degree of Civil Engineer.

Mr. Rowland entered the employ of the Continental Iron Works immediately after graduating, and remained continuously with that company, holding the position of assistant treasurer at the time of his death.

He was an active member of several scientific and patriotic societies, and was especially identified with the management of Webb's Academy and Home for Shipbuilders, New York, being a member of the Governing Board. He joined the Society as a Junior Member in 1887 and as a full Member in 1894.

Mr. Rowland died July 7, 1907 after an illness of several months.

THOMAS FITCH ROWLAND

Thomas Fitch Rowland was born in New Haven, Connecticut, March 15, 1831. He was the son of George Rowland and Ruth Caroline Attwater, and a lineal descendant of the Honorable Thomas Fitch, the last Colonial Governor of Connecticut.

He attended the public schools of his native city until he was 13 years old, when he entered his father's grist mill, becoming the miller's boy.

Upon the construction of what is now the New York, New Haven and Hartford Railroad, through the city of New Haven, the mill was demolished, and he entered the employ of the railroad, and was its first apprentice in the machine shop. While in this employ he fired the third passenger train that was sent over the road from New Haven to New York.

In 1850 he left the employ of the railroad company and was appointed second assistant engineer of the Connecticut, a large side-wheel steamboat plying in the service of passenger and freight transportation between the cities of Hartford and New York. Soon after joining the Connecticut, the line was sold, and all employees in the engineering department of this steamer were discharged.

He then obtained a situation with the Allaire Works of New York, an old established engine building concern, and while there designed the engines for the U. S. Revenue Steamer Harriet Lane. In the course of time a change of ownership of the establishment occurred, and he resigned and accepted a position at the Morgan Iron Works. at that time owned and operated by George W. Quintard. There Mr. Rowland was given a commission by Mr. Quintard to prepare designs, specification and estimate of the cost of producing the machinery to be installed on board the U. S. gunboat Seminole then under construction at the Pensacola Navy Yard. Mr. Quintard obtained a contract to build this machinery, and Mr. Rowland was to take charge of the work, prepare the drawings and details of construction, and superintend the execution thereof, from its commencement until final completion. While engaged upon this work he became acquainted with Capt. James L. Day, formerly of Norwich, Connecticut, who was interested in steam vessels on the Mississippi river, about the waters of New Orleans and Lake Pontchartrain, and was negotiating with Mr. Quintard for the construction of an iron side-wheel steamboat, similar to those in use about the city of New York. Mr. Quintard eventually obtained a contract for the construction of this vessel, and Mr. Rowland was engaged by him to superintend the work. Associated with him was Mr. Samuel Sneden, a prominent builder of wooden vessels of that day. The vessel was built at Greenpoint, Long Island, and Mr. Sneden formed a partnership with Mr. Rowland for the building of wooden and iron steamships, steamboats and other structural iron work.

The first contract the new firm obtained was an order from the Croton Aqueduct Department for the building of a wrought iron water pipe of large diameter, one-quarter of a mile long, to be located on the top of the High Bridge, over the Harlem river.

One of the early contracts received by this firm was that for an iron vessel, designed by the late Captain John Ericsson. During the partnership with Mr. Sneden, the wooden hull of the side-wheel steamboat Continental, for the New Haven Steamboat Company, and the hulls for the steamboats City of Boston and City of New York, for the New York and Norwich Transportation Company, were built. Mr. Sneden severed his connection with the firm in 1860, and Mr. Rowland afterwards conducted the business under the name of The Continental Works. Early in 1861, during the commencement of the Civil War, he obtained a contract for the construction of a number of naval gun carriages. He also constructed for the Navy Department nineteen or twenty revolving platforms or mortar bed carriages. These revolving mortar beds, with their surmounted mortars, were installed on board a complement of vessels which became known as the Porter Mortar Fleet.

In 1861 a second contract was made with the late Captain John Ericsson and his associates, for the building of an iron clad floating battery, afterward known as The Original Monitor. Upon the completion of The Original Monitor, he built the monitors Montauk, Kaatskill and Passaic, also the double turreted monitor Onondaga, and the light draft gunboats Cohoes and Muskoota. In 1870 he built the ferryboats Fulton and Farragut, for the Union Ferry Company, and subsequently, the boats Atlantic and Brooklyn, for the same company.

For many years Mr. Rowland was engaged in the design and construction of gas manufacturing plants in various parts of the country, notable among them being those of the Commercial Point Station of the Boston Gas Company, and also of the Twenty-first, Forty-fourth and Ninety-ninth Street Stations of The Consolidated Gas Company of New York. In 1887 the business of Mr. Rowland was incorporated as The Continental Iron Works, of which corporation he was the President up to the time of his death. In the early days of this corporation he designed and constructed a gas holder and steel tank, located at the Fourteenth Street Station of The Consolidated Gas Company of New York, which, at that time, was the largest of its kind in this country, and was a noted achievement in gas engineering.

For many years previous to 1887, Mr. Rowland devoted much time and thought to the art of welding iron and steel plates in various forms and shapes, and it was about this time that he designed the process, and also the apparatus, used by The Continental Iron Works in the manufacture of the Fox Corrugated and Morison Suspension furnaces, which are now universally used in the internal furnace type of boiler, so well known to engineers and boilermakers.

Mr. Rowland had been in failing health for some considerable time, but continued to be active in the business until a few months ago. He was also actively interested in many charitable and philanthropic enterprises. Mr. Rowland married in 1855, Mary Eliza Bradley, of New Haven, Connecticut, who died in March, 1902.

He was a member of many years standing of various engineering societies, clubs, etc., notably,

Honorary Member—The American Society of Civil Engineers, Society of Gas Lighting, Union League Club, American Yacht Club.

Life Member—The American Society of Mechanical Engineers, Society of Naval Architects and Marine Engineers, New Haven

Colony Historical Society, Fairfield County Historical Society, American Geographical Society, New England Society, N. Y. Chamber of Commerce, American Gas Light Association.

Trustee—Webb's Academy and Home for Shipbuilders, General Society of Mechanics and Tradesmen, New York Historical Society.

The funeral services were held at the Church of the Heavenly Rest, Fifth Avenue and Forty-fifth Street, on Monday, December 16, and the burial was made in the family plot in Evergreen Cemetery, New Haven, Connecticut.

WILLIAM L. SIMPSON

William L. Simpson was born in Philadelphia, March 25, 1847, and spent his early life in Chester, Pa., serving an apprenticeship with the firm of Reany, Son and Archbold. He was engaged in the merchant marine service for several years, during which time he was engineer on the steamer Juanita of the Southern Mail Steamship Company, off the Coast of Florida Keys in 1870. Later he was connected as erecting engineer with the Scott Foundry of Reading, Pa., and for four years was superintendent of the Dickson Manufacturing Company in Wilkesbarre, remaining with them until 1877, leaving there to take charge of the Baine and Huston Works in Philadelphia. He was associated with the Buckeye Engine Company of Salem, Ohio, and organized a shop in Philadelphia in 1880 for the manufacture of engines for the eastern market. Afterward he became general Eastern sales agent for the Buckeye Engine Company. Mr. Simpson joined the Society in 1890. He died February 1, 1907.

CHAS. K. STEARNS

Chas. K. Stearns died in the city of Boston, May 12, 1907. He was born at Newton Centre, Mass., in 1864 and was educated in the Newton public schools, and at the Massachusetts Institute of Technology, graduating in 1887. He was engaged by the Thomson-Houston Electric Company at Boston and later was manager at their St. Paul office. He was assistant engineer in electrifying the Nantasket Beach branch of the New York, New Haven and Hartford Railroad, and during his later years had continued in similar work with street railways and the electric development of water powers. Mr. Stearns joined the Society in 1899.

NORMAN C. STILES

Norman C. Stiles was born in Feeding Hills, Mass., June 18, 1834. He received a common school education, and at an early age took up design and construction at the American Machine Works, Springfield, Mass. He invented and developed many machines for stamping and drawing sheet metals, secured patents on the punching press, drop hammers, and similar machines, and continued their manufacture until 1884. He designed and patented most of the machines now manufactured by the Stiles & Parker Press Co., of Middletown, Conn., of which company he has been the principal owner, treasurer, and manager since its formation in 1871.

Mr. Stiles became a member of the Society in 1884, and subsequently became a life member. He was elected manager in 1895 and served on the Council until 1898. He died February 4, 1907, at his home in Hartford, Conn.

HERMAN UNZICKER

Herman Unzicker was born June 7, 1846, in Hessen Nassau, Germany. His preliminary education was received in a technical school, and he served an apprenticeship of several years in a machine shop, later attending a technical school in the State of Brunswick, Germany. Upon leaving school he was engaged as draftsman and designer in several machine shops, and had charge of works as mechanical engineer and foreman.

He came to the United States in 1872 and found employment as draftsman in Chicago, Ill. In May, 1888, he became general superintendent and engineer of the shops of Fraser & Chalmers, Chicago, Ill., with which firm he remained 14 years, as designer and constructor of plants and machinery for the mining and reduction of all classes of ores.

In 1890 Mr. Unzicker organized the Chicago Iron Works, which, however, succumbed during the panic of 1893. Since that time he has been contracting and consulting engineer with E. P. Allis & Co., Fraser & Chalmers, and the Allis-Chalmers Co. At the time of his death, February 7, 1907, he was consulting engineer with Chalmers & Williams.

W. H. WIGGIN

W. H. Wiggin was born at Dracut, Massachusetts, May 7, 1861. He attended the public school at Chelmsford and the Academy at New Hampton, graduating in 1879.

His apprenticeship was served in a repair shop at Greenville, New Hampshire, and later he was employed by the Fitchburg Machine Company, the Putnam Machine Company, and various other shops at Fitchburg, Mass. In 1883 he was given charge of the Lamson

Cash Railway Company, Lowell, Massachusetts, and at this time took out a patent for improvements on cash railway systems for stores. In 1886 he was employed by Charles H. Morgan of Worcester, Massachusetts, on special work in developing new machinery. A year later he was engaged as mechanical man in a factory manufacturing medical capsules, afterwards returning to C. H. Morgan, at Worcester, where he did erecting work on rolling mills, and designed new machinery.

Mr. Wiggin was subsequently engaged with G. L. Brownell, and the H. C. Pease Machine Company, the old Washburn & Moen Manufacturing Company, Marcus Mason and Company and the Richardson Manufacturing Company and at this time designed a new mower for the rocky hillside farms of New England. In 1903 he became mechanical assistant superintendent at the Deering Division of the International Harvester Company, and was advanced to the position of master mechanic in the construction and equipment division. He remodeled and reëquipped the old Milwaukee Harvester Company plant for the manufacture of gasolene engines and cream separators. In 1905 he was transferred to Hamilton, Ontario, as superintendent of the Canadian plant, and held this position until his death, October 2, 1907.

Among Mr. Wiggin's most important inventions was a rail bond which is used on electric roads and an automatic machine for making bicycle spokes and similar products. He was a member of the Masonic Order, and of the Canadian Manufacturers Association.

THOMAS HILTON WILLIAMS

Thomas Hilton Williams, President of the A. A. Griffing Iron Co., Jersey City, N. J., died Saturday, October 19, 1907. Mr. Williams was born February 14, 1848, at Springfield, Mass., and early in life removed to Jersey City, N. J., where he subsequently became identified with the iron and brass metal industries. He graduated from Packard's Business College of New York and after a short experience in the banking business became a partner in the E. A. Williams and Son Brass and Bell Foundry of Jersey City. At the time of his death he was president of E. A. Williams and Son, Incorporated. Mr. Williams was perhaps best known through his long association with the A. A. Griffing Iron Company, makers of "Bundy" Radiators. He became an officer in that company at a time when cast iron was first used in radiators for steam and hot water heating.

He was a member of The Engineers' Club, the Lawyers' Club of New York, the American Geographical Society of Washington, D. C., and the Carteret Club of Jersey City, N. J.

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NOTE

1 Names of authors of papers, discussions and addresses are in CAPS AND SMALL CAPS.
2 Full or a breviated titles of papers are in *Italics*, except when following the names of discussors.
3. The Society is not responsible as a body for the statements of fact or opinion in its papers and discussions.