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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Twentieth Annual Convention.

Niagara Falls, N. Y., June 29–July 3, 1903.

MONDAY—MORNING SESSION.

President Charles F. Scott called the convention to order in the auditorium of the Natural Food Company at 10:30 A. M.

President Scott:—During the past year, when it became necessary to determine the place at which to hold this convention, we had cordial invitations from a number of cities, but for one reason or another there seemed not to be sufficient and satisfactory reason for accepting any of them. The chairman of our committee asked me what to do. I said: there is one place in America which seems to me to be pre-eminently the convention city; it is central; it has unsurpassed natural attractions; it is accustomed to holding and receiving large numbers of people and important conventions, and, more than that, it is a place where we may go and be independent; while we would be glad to receive such courtesies as might be freely extended we would feel that we were not imposing ourselves upon any of our local membership.

I take pleasure this morning in presenting to you the mayor of this famous city, a city far-famed throughout this whole world not only for its unexcelled natural surroundings, but also for its pre-eminence as an electrical city—Mayor Hancock.

Mayor Hancock:—Mr. President and gentlemen.—Since I have been mayor of this city I have had the pleasure of offering the glad hand of welcome to many conventions. I even tried a short time ago to welcome a distinguished French gentleman who was visiting here, but as I couldn't talk French and he couldn't understand English, we didn't hit it off very well. But I want to say that I have never had the honor of presenting the freedom of the city and the whole bunch of keys to a more distinguished convention than this one before me. While I have been growing up to my present magnificent proportions many changes have been taking place in this town. When I was a boy this place consisted of two villages containing seven or eight thousand people, Niagara Falls and Suspension Bridge. Every year about

May 1, Niagara Falls woke up. Some of us took down the shutters, dusted off the feather fans and the Indian beadwork and the pieces of table-rock brought over from England and prepared to offer them for sale to the gentle stranger at reasonable prices. Others of us shoved out the family hack, shook the kinks out of the horses' legs, drove down to the hotels and depots and offered that same gentle stranger a ride around the Falls for five cents, expecting, of course, to get all the traffic would bear when that lovely ride was over.

Some eighteen or twenty years ago Mr. Gaskill and Mr. Evershed, the former a flour miller and the latter an engineer of Rochester, sprung the idea of harnessing the Niagara. They started out to raise the wind, but had the wrong kind of bellows, I guess. A little later Mr. W. B. Rankine and his friends took up the project, the result being that to-day Niagara Falls is a prosperous city of 25,000 people, with many large factories, and its development in the electrical line, I think, has only just begun.

I trust, gentlemen, you may have a pleasant week and enjoy yourselves. I thank you.

PRESIDENT SCOTT:—In the arrangements for a meeting of this kind there are a great many preliminary labors, usually on the part of painstaking men who are not much in evidence. The man who has had this convention at heart through the year, who made the preliminary arrangements and who has looked after the papers for this meeting, is Dr. Sheldon, the chairman of the Papers Committee, to whom a great deal of credit is due. A few months ago, when it became necessary to make the specific arrangements, Prof. Sever was called to the chairmanship of the General Committee to have in charge the arrangements for this convention. As chairman of the local committee, Mr. H. W. Buck was selected. The success which may come to this meeting is largely due to the efforts of these three men, seconded by the members of their committees.

I announced the names of three gentlemen who have been prominent in arranging for this convention. There is another that I omitted. We may omit him because we take him for granted. He is active all the time—the Secretary.

President Scott then read his annual address as follows:

THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

President's Address—June 29, 1903.

CHAS. F. SCOTT.

The engineer is defined as " one skilled in the application of the materials and forces of nature to the use of man." Once he dealt almost wholly with materials—some do so still, arranging brick and stone and iron to form bridges or buildings which stand inert. Others combine materials and forces. But the electrical engineer deals with forces, with energy in its moving, kinetic form. His unit is not one of length or mass or volume or strength—it is the kilowatt, a unit of activity. If the flow of energy cease, the electrical system is inert, as useless as the body when life is gone. He energizes and vitalizes the systems constructed by engineers of many kinds. Hence the phenomenal rate of electrical extension—it is not a new thing separate and apart from other things, it enters into them, it operates, it awakens, unites, transforms.

Among the various branches of engineering many are of old standing and have been developed during many years; the greater part of what is standard to-day may be found in the text books and the treatises of a generation ago. On the other hand, the second edition of Kapp's " Electric Transmission of Energy " which is less than fourteen years old contains no reference—other than a sentence in the preface—to the commercial use of alternating current, although it has already become well-nigh universal. If one were about to install a long distance transmission plant he could call hydraulic engineers as advisers, who have had many years of experience. But he would find that electrical engineers have had scarcely any experience with the high voltages which are now being introduced. In fact the plants which have been operating at 40,000 volts for more than two years may be counted upon the fingers of one hand or even upon the thumb.

The newness of electrical work is shown also in our large cities which depend for their street railways, for their light and for their power upon apparatus in central stations and upon methods of transmission which were unknown a dozen years ago.

The electrical reports in the U. S. Census show that the mean rate of increase in electrical activity as measured by the capital invested is 20 per cent. each year—it doubles in four years.

Technical schools, electrical courses and laboratories have increased wonderfully, but their output of young engineers does not supply the growing demand.

Note how electrical and other interests are interdependent. The underground railway systems in New York City require the work of almost every branch of engineering. The purpose of the whole is the operation of trains. Everything contributes to that end. The operation is by electricity. So also does every department of the system come into relation with the electrical engineer; the design of the power house, of the locomotives or motor cars, of the tunnel, of the track, of the stations, the arrangements for handling passengers—all are related in some way to the electrical system. And naturally so—they all are the passive elements contributing to the one active end, train operation, and electricity is the immediate active element by which trains are operated. Hence, in general, all else is adapted and contributes to the electrical system and must harmonize with it. Hence the electrical engineer is the central engineer, he more than any other comes in contact with all; he more than any other needs to know something of all other departments and professions.

Just as the workmen in a factory depend upon tools and motors and transmission circuits and buildings in order to do their work, so also does modern society depend, for that something which we call commercial and social life, upon mills and factories, upon facilities for travel and communication and upon its bridges and its buildings, its engines and dynamos—all, the results of engineering work. We know all this, we know that the new attitude toward nature beginning with the achievements of Copernicus and Galileo and Newton marked the beginning of new methods of thought and of action. We know that mechanical power by means of the steamship and the railway train has had the most profound effect upon modern life in every particular—commercial, industrial, social, political. We recognize the new impetus which has been imparted by electricity during the past score of years. We know all these as physical facts and we see their immediate effects. But we are so surrounded by them and they are so close upon us at every hand and we have become so accustomed to them that I question whether any of us appreciate and realize their full significance. The immediate effects are readily seen. It is the indirect but far-reaching influence of the new agencies which is not so easy to discover.

In this new era the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS represents the profession which is youngest in years yet foremost in activity. To meet the present demands of this new era, to prepare for an expanding future, we may well ask, What should our INSTITUTE be? What should it do? Shall we adopt the methods of the old-time learned society? Shall we imitate the ways of societies or professions whose methods are established and whose rate of change is slow? Shall we reserve preferment for those with hoary locks or well-rounded years of experience?

Not only the activity of our profession but the spirit of the times demands something different. We cannot stand aloof, we cannot be exclusive—we must recognize that we are in a new era with its unprecedented rate of progress. We cannot wait till men develop through many years of experience, for they are needed quickly—how then can we increase the efficiency of their training and accelerate their development? We have no long record of achievement and experience to guide; we must execute and operate in a dozen places what has scarcely had time to demonstrate its success in its first installation—how then can we increase the efficiency of our work by extending the knowledge of that which has been done and by crystallizing from present practice that which should be made standard?

A year ago when your votes imposed the responsibilities of the presidency upon me, it seemed that while the preceding year had fixed a high standard for our monthly meetings in New York, we should develop next some method by which distant members might take much more active part in our work. I took up the conditions confronting me as a definite problem. I studied it and discussed it with others; it grew, and new phases appeared. The problem as it presented itself to my mind together with certain specific ways for advancing our interests were set forth in an address upon " Proposed Developments of the INSTITUTE " which I read at the beginning of the year. I may add now that the more deeply I have become involved in the affairs of the INSTITUTE the more interested have I become and the greater have its possibilities appeared.

In that address of last September several specific ways were proposed by which the work of the INSTITUTE might be advanced during the year. Let us review them briefly, noting their bearing upon the future.

(1) " The membership should be increased."

My own convictions were expressed during the year in the following words: " We have failed to catch the spirit of the times and the keynote of electrical progress if we do not realize that we must expand and broaden and progress as well as maintain high standards of excellence. Full membership should be exclusive, associate membership should be inclusive."

Our membership list on September 15, 1902, included 1630 names. Since that time nearly 1000 applicants have been elected as Associates. Who are the men who have come among us? What is their age, what has been their training, what is their present position?

The new men range in age from 19 to 65. The ages of those who have been elected are given in the following table:

Over 50 years	2%
45 to 50 years	2%
40 to 45 years	6%
35 to 40 years	10%
30 to 35 years	24%
25 to 30 years	34%
20 to 25 years	21%
Under 20 years	1%

Approximately 60 percent are between 25 and 35 years of age and are presumably young men who are getting under substantial headway in life and are in their accelerating period.

Forty-four percent of these men are graduates of schools of recognized standing. Of the graduates 45 percent graduated within the past 5 years (not including 1903), and 77 percent within the past 10 years. Cornell University leads the list with 12 percent of the graduates; the Massachusetts Institute of Technology is second with 8 percent; Columbia, Purdue, Ohio State, Princeton, Worcester Polytechnic Institute, Lehigh, University of Michigan and the University of Wisconsin follow next and there are substantial numbers from McGill, Stevens Institute, University of Pennsylvania, University of Illinois, University of Minnesota, Pennsylvania State College, University of Nebraska, University of California, Harvard, Yale, and Rose Polytechnic Institute. In addition there are graduates from numerous additional institutions, as well as many others who have not taken degrees.

The position and occupation of the new members is difficult to classify definitely, but a general summary shows the following:

Electrical engineers with manufacturing companies	30%
Electrical engineers with operating companies	25%
Managers and superintendents, duties presumably executive rather than technical	16%
Consulting engineers	10%
Electrical engineers with mills, mining plants and the like	6%
Students	6%
Professors and instructors	4%
Mechanical and electrical draftsmen	3%

I think we may congratulate ourselves that our additions are truly representative of the electrical engineers of America, including not only those advanced in the profession, but young men of promise—the engineers of the future. An addition of 60 per cent. to our numbers in a single year principally of men who are entering active engineering work and who have been attracted to the Institute because they believed that it was well worth while to join, means much to the Institute, it means much to the men and it means much to the electrical engineering profession.

Other plans proposed at the beginning of the year were that:

(2) " Papers and discussions should be contributed from a larger proportion of the membership."

(3) " Local meetings of the Institute in various cities will broaden the interest of its work and generally extend its benefits."

(4) " Universities and technical schools with electrical engineering departments may organize local meetings of the Institute."

These three lines of activity have developed most satisfactorily and are closely related to each other. General plans were presented for the formation of local branches and such branches have been formed among members in a number of leading cities;

also in many of the principal technical schools and universities. In some cases local members and students unite. The methods have been simple: there is a minimum of organization and formality; the primary purpose is to bring electrical men together, to awaken interest, to consider and discuss important engineering topics. At the beginning of the year definite subjects were assigned for each month for the meetings in New York. Usually several papers were secured from experts upon each subject. Printed copies of the papers, together with the stenographer's report of the New York discussion have been sent promptly to the secretaries of the local branches. As the branches have usually held their meetings subsequent to the meeting in New York, they have had the advantage over the first meeting in having the discussion as well as the papers. This material is presented in suitable form by the members of the local branches and the discussion is continued. Such material as is new and valuable is reported to the Secretary for publication in the TRANSACTIONS. By this means the latest phases of electrical engineering work are presented and discussed not in one meeting only but in more than a score.

Those who have taken up the local work usually report that the interest, the activity and the attendance surpass expectations. In nine cities in which local branches have been formed the total membership has practically doubled. The attendance is not limited to members, as others are welcome. A number of professors have spoken of the interest taken by students and the avidity with which they enter into the work. One professor recently remarked to me that the INSTITUTE papers were giving him a new insight into present electrical engineering and such papers as those upon Central Station Practice made him realize how far practical engineers were in advance of the lecture room and the laboratory.

The element of greatest importance in this extension of our work is to my mind not so much the mere technical knowledge which it may diffuse but the broader aspects of up-to-date problems which it presents and the sentiment of unity and coöperation among electrical men. Electrical engineers have not the advantage of long-time acquaintance, but in this plan we have an effective means of bringing them together, of uniting them in a common interest and of directing the studies and the work of young men along definite and effective lines.

At the beginning of the year it was indicated further that:

(5) " The collection of engineering data and the establishment of standard practice in electrical engineering is one of the important functions of the INSTITUTE."

The present years are formative years. Electrical engineering is crystallizing. In addition to our Committee on Standardization two new committees have been formed, one on High-Tension Transmission, the other on Engineering Data. The Transmission Committee is composed of engineers of recognized standing. A consulting engineer is the chairman, and representatives from several large manufacturing companies and a western university complete the committee. This committee is collecting specific data with respect to present practice in high-tension transmission and will formulate these data for the use of electrical engineers. It has further prepared a number of short papers as introductions to discussions upon a number of important branches of transmission which is calling forth the opinions and experience of engineers at large.

The Committee on Engineering Data is composed of men of high standing, under the direction of the Electrical Engineer of the Niagara Falls Power Company. It has been appointed for collecting and publishing electrical engineering data upon new and special subjects which are evolving daily throughout the country in the practice of the engineering profession. There is much important data which have not found their way into text books and hand books and about which little is generally known. Such data, if allowed to follow existing channels, either never reach the public, or only after a long period. The first subject to be taken up for investigation is insulated electrical conductors. Under this general subject is included the heating of cables of various character under different conditions, the life of cable insulations, the methods of ventilation in conduits, the effects of short-circuit, and general data bearing upon the operation of cable systems.

I count such work as has been undertaken by these committees as of the highest importance to the INSTITUTE and its members, for it deals with matters vital to substantial electrical progress. They are the means of carrying out one of the highest functions of the INSTITUTE in bringing together the diversified achievements of many workers which in the aggregate constitute a single total of accomplishment which we designate as progress. They bring definite and systematic results out of what is otherwise indefinite and chaotic. Thus they lay the foundation for advancement.

As a further department of our work it was stated at the beginning of the year that:

(6) "Our library merits a cordial support." The generous contributions of members have been continued during the year by substantial additions to our valuable collection, not only in contributions of present volumes but in endowment provision for the continuation of sets which have been presented. Plans are now under consideration for giving our own TRANSACTIONS —a panoramic history of American Electrical Engineering— greater value by preparing a general index to be issued both in pamphlet form and also on cards, which may be distributed alphabetically through the card catalogues of public and private libraries.

The crowning event of the year was in a measure anticipated by these sentences of last September:

(7) "Permanent quarters for the INSTITUTE should be an object of plans and anticipations. * * * Personal acquaintance and social intercourse are influential factors in unity of sentiment and of action."

The story of our Library Dinner with its distinguished guest who spoke in happy mood of American engineers and of coöperation among them and of "institutions like this of the Electrical Engineers which do so much" is already familar to you, as well as the events of the following day when he called to his house two of our members to talk further of what an engineering building should be and of plans for its realization. I count as the most memorable privilege of the present year the opportunity given me of sitting next to Mr. Carnegie on the evening of our Library Dinner and the hour in his own library on the following afternoon. At the dinner he was in the best of spirits, alert, and ever interesting as conversation shifted easily from one topic to another. The talk was pleasant and appropriate to the hour but never trivial. One topic after another came up, but it was the more serious, the more definite, the substantial idea which he brought out before turning to something else. The happy response to his toast was almost throughout a repetition of the ideas and the sentiments which he had expressed in the conversation of the preceding hour.

In discussing at his house the next day the project of an engineering building he impressed me as seeking the way by which he could realize an ideal. He was not very familiar with the organization of the several engineering societies, he knew little of their methods and of their financial means and their facilities. But he saw a need, not merely the physical need of accommodations, but the higher need of elevating and developing engineering and engineers. He used about these words: "Yes; engineers need to get together, they need to get acquainted and to meet socially. You can provide for that, can you not?" In his address as President of the Iron and Steel Institute since that time he has discussed methods of industrial organization, particularly the relations between men, and he has emphasized the advantages of a general partnership and common coöperation. When, a few days after our first conversation, estimates and a general scheme of procedure were presented, Mr. Carnegie did not care to go into the details of method. He seemed to have confidence that engineering organizations could develop their plans in the ways which would be most efficient. He set no restrictions. The great Gift to Engineering is presented in a single sentence shorter even than the superscription of the letter which proffers a million dollars. Four of the organizations (the fifth has not yet taken final action) which were designated in his letter have without hesitation formally accepted the administering of this generous gift to engineering and their representatives are now actively developing plans. These plans look forward to the realization of an ideal long cherished by some of the foremost and far-seeing engineers of the country, an ideal in harmony with the new era in engineering and with the trend of American development, an ideal which brings within its scope the advancement of the engineer and of his profession both within itself and in its outward relations. In short, an ideal the realization of which will strengthen modern engineering—the very basis of national prosperity and progress—and will exert influences which are beyond our power to discern.

The remaining specific way mentioned at the beginning of the year for advancing the interests of the INSTITUTE was:

(8) "Coöperation with similar institutions in other countries."

Our relations with the Institution of Electrical Engineers of Great Britain in particular are most cordial and beneficial, and we are planning to have its members with us at the time of the Engineering Congresses to be held at the St. Louis Exposition next year. But the idea of coöperation has had its development along domestic rather than foreign lines. It is not worth while here to recount the advantages of coöperation. We recognize it as the modern method. The possibilities which may come through coöperation among engineers and in engineering work are hardly less than those which are recognized in industrial. commercial. financial and social affairs. The founding of the John Fritz medal, and the gift of a Union Building are magnificent examples.

In the interrelations between societies, care must be taken that individuality and freedom for individual development are unrestricted, and that the points of contact and common endeavor are only those in which the most efficient results can be obtained through coöperation. I think all will agree that just as electricity has been pre-eminently a unifying element in modern affairs, so also the electrical engineer should be a unifying element in the engineering profession and that there should be in particular a coöperation among electrical organizations. Let us develop the ideal and then realize it as best we may, step by step, in the future.

To present definitely a general scheme I will give the substance of a suggestion which I presented to our Committee on Affiliated Societies which now has the general subject under its consideration.

First.—A plan should be outlined providing for special departments or sections of the INSTITUTE for such lines of electrical work as may demand greater attention than can be given by the INSTITUTE as a whole and which can be more efficiently conducted in this manner than by the formation of new specialized societies.

Secondly.—Affiliation or coöperation is desirable with other electrical associations by which the INSTITUTE may work in harmony along certain lines, such as Standardization, adoption of the National Electric Code, the Collection of Engineering Data and other matters of a general nature. Many associations dealing with specific industries have both commercial and engineering interests. I would make the INSTITUTE the electrical head or center, bringing into a unity the electrical engineering of all these associations, not restricting, but broadening their work and making them constituent parts of a great whole.

Thirdly.—There is opportunity for close relations between our local branches and local engineering societies or clubs. In two or three cities the local societies are considering plans of uniting sections of their societies with local branches of the National Societies. Think for a moment of the possibilities in elevating the work and increasing the efficiency of engineering organizations by establishing close ties between local and national societies—keeping them in close sympathy and coöperation, and bringing them into one great system! The success which has attended our branch organizations augurs well for further extension by similar methods for awakening and stimulating a general interest in engineering subjects.

Fourthly.—There should be coöperation—without affecting their present individuality—between national engineering societies in the nature of a National Engineering Congress for promoting closer relations between the various branches of engineering work and for representing the engineering profession as a whole.

In this summary review of the year's work no mention has been made of less conspicuous though scarcely less important matters—the Committee on Finance, the Committee on Papers, the Editing Committee, the Board of Examiners, the Committee on National Electric Code, the Reception Committee, the Committee on Membership, the coöperation of the INSTITUTE in the establishment of the John Fritz Medal, the plans of the INSTITUTE for the Louisiana Purchase Exposition, the extension of certain privileges to students in electrical engineering upon the payment of a small fee, the plans for receiving graduating theses and according recognition to those of superior excellence. On the Board of Directors and the Committees are earnest active men who have freely contributed time and labor to the advancement of your interests. After all, the element which promises most for our future is the spirit of the men who are leaders in our work and the ready response to their efforts which has come both from our members in carrying out our work and from those who have come in such generous numbers to join with us.

It is difficult to see wherein our work can be materially reduced without serious loss. It is easy to see how it may be expanded. I emphasize particularly the establishing of permanent committees to be continued from year to year to carry on lines of work such as the committees on standardization, on transmission, and on engineering data. The value of the results is unquestioned, but the amount of work necessary is not so readily appreciated. We must depend for our best work upon the men who are busiest and who are in a way least able to give it. We must efficiently utilize small contributions of endeavor and assistance from many men. This requires organization and direction, these men should have the fullest assistance from others who are paid to carry out their directions and to care for details.

Our expenses are within our income simply because we have been watchful, restricting expenditure at every turn. In order to expand and to carry out the lines of work which are most valuable to ourselves as individuals and for the substantial promotion of electrical engineering and of electrical industries, we need money.

In the Union Building for the Engineering Societies, it devolves upon the societies to provide the land upon which the Carnegie gift is to be placed. To provide for the INSTITUTE in this matter, a committee has undertaken the raising by subscription of a fund for this purpose. This magnificent supplement to what Mr. Carnegie is doing will give the INSTITUTE rent-free its building for general meetings, for library, for offices, reading and reception rooms and the like. This will enable us to devote to technical purposes the funds which would otherwise be required for rent, which are considerable now, and would be greater in the future.

We anticipate substantial contributions from those who have reaped a rich reward from the applications of electricity. Their wealth has come in no small degree from the work of electrical engineers. Whatever the INSTITUTE may do in raising the standards and increasing the effectiveness of electrical engineering brings rich returns to those men and particularly to those companies commercially interested in electrical pursuits. The farmer saves from his surplus the best seeds for the coming season—should not some of the wealth which engineering effort has produced be returned to train men and to develop methods for the future? Is not the wholesome recognition of the engineering profession by Mr. Carnegie coupled with his generous gift but the beginning of a new attitude toward engineering and of better things to come? Engineering researches and investigations and tests requiring large sums of money should be undertaken. It is not too much to hope that if we use well the talent which has been given us, more may be entrusted to our keeping.

But building and library, professional papers and technical data are only the facilities, the means, the tools, for the men who are to use them. We must develop men, more effective men. Let us maintain high standards of excellence, of professional attainment and of integrity. This does not require that we be too exclusive, holding ourselves aloof and apart. In religion the ideal is no longer the monk in the cloistered cell, it is activity in daily life. Electrical engineering is in contact with many interests, let electrical engineers be in touch with many men. In one sense engineering and commercialism are widely apart. Yet there is a commercial side to engineering, not mere selling, but the adaptation of engineering work to definite industrial and commercial conditions in such manner as to bring the best results. In our papers we do not discard subjects which are of engineering interest and value, simply because they may be of financial importance to some one. It is not our function to treat simply of the things which are of no value to anybody. Yet our criterion is not commercial, but engineering; practical common sense, not sentiment, must prevail in our relations to things and to man. The engineer is not merely the man in the closet surrounded by slide-rules and tables. Electrical enterprises depend upon manufacturers, industrial captains and financial managers—upon those who construct and apply and use and direct the results of engineering work. Engineers should know these men and work in harmony with them. The plan for the new Union Building—the Capitol of American Engineering—not only brings engineers of different professions together but it recognizes broader relations, as the engineering societies will be adjacent to a social club " composed of engineers and others who may be interested in or connected with the engineering profession."

We are in an engineering age, an electrical age, with its physical commercial, industrial and social changes, with its new conditions, new opportunities and new responsibilities. And these are the beginnings of yet greater things to come. Let us be awake to the times and in touch with modern methods. Let us make the work, the methods and the ideals of our INSTITUTE in full harmony with that profession which deals with kinetic energy and whose units of measure are the units of activity and whose mission it is to awaken, to energize, to unite, to transform to operate, to make effective.

*A paper presented at the 20th Annual Convention of
the American Institute of Electrical Engineers,
Niagara Falls N. Y., June 29th 1903*

ENERGY TRANSFORMATIONS IN THE SYNCHRONOUS CONVERTER.

BY WM. S. FRANKLIN.

CONTENTS.

1. INTRODUCTION.

The engineer ordinarily approaches the study of the synchronous converter with ready made knowledge of the direct current dynamo and of the alternating current dynamo. The result is that the action of the synchronous converter is usually described in terms of the activities of the synchronous alternating current motor and the direct current generator, and the theory of the synchronous converter is usually developed in terms of those notions which apply primarily to the synchronous alternating current motor on the one hand, and to the direct current generator on the other. As a matter of fact, the *external electrical relations* of the synchronous converter may be completely represented by this method of attack. When, however, the synchronous converter itself—its *internal activities*, as it were—is the object of study, the notions of the synchronous alternating current motor and of the direct current generator do not suffice. There are certain elements of behavior of the synchronous converter which are foreign both to the synchronous alternating current motor and to the direct current generator; to examine into these elements we must attend to the actual physical activities of the synchronous converter without regard to the mathematical analysis of these activities into their more or less fictitious and unreal component parts, namely: synchronous motor activities and direct current generator activities. I give in a subsequent section of this paper a statement of the criterion which enables one to judge of the physical reality or unreality of the component parts into which a physical aggregate is resolved by mathematical analysis, and it suffices here to state that this criterion shows the physical unreality of synchronous motor activity and direct current generator activity as component parts of the activity of the synchronous converter.

2. THE SYNCHRONOUS CONVERTER COMPARED WITH THE AUTO-TRANSFORMER. STATEMENT OF OBJECT OF THIS PAPER.

Let *b* Fig. 1 represent one of the d.c. brushes of a two-ring converter. Let this brush be chosen as the zero or reference point of potential, and let *d* represent the other d.c brush. Let *r* be the position of the a.c tap at a given instant. This tap *r* is at a potential which is between the potentials of *b* and *a* Let *i* be the instantaneous value of the alternating current entering at *r*. A portion, *A*, of this current *i* flows up hill, as it were, from *r* to *a*, receiving energy because of assistance due to the induced electromotive forces in the windings between *r* and *a*. Another portion, *B*. of the current *i* flows down hill from *r* to *b*, giving up energy because it is opposed by induced electromotive forces in the windings between *r* and *b*.

Let *b*, Fig. 2, represent one of the service mains to which alternating current is supplied by an autotransformer. Let this main be chosen as the zero or reference point of potential. and let *a* represent the other service main Let *r* and *r'* be the two supply mains. The main *r* is at a given instant at a potential which is between the potentials of *b* and *a*. and the current *i*, which enters at *r* at the given instant divides into two parts. *A* and *B*. The portion *A* flows up hill, as it were, to *a*, receiving energy because of assistance due to the induced electromotive forces in the windings between *r* and *a*. The other portion, *B*, flows down hill, from *r* to *b*, giving up energy because it is opposed by induced electromotive forces in the windings between *r* and *b*.

The energy received by the current A as it is boosted up from *r* to *a* is in general equal to the energy which is delivered by the current B which flows down from *r* to *b*.	The energy received by the current A as it is boosted up from *r* to *a* is equal to the energy which is delivered by the current B which flows down from *r* to *b*.

In the auto-transformer a definite portion of the energy which is transferred from the supply mains to the service mains is transferred by virtue of the conductive connections between supply mains and service mains through the windings of the transformer. In the synchronous converter, also, a definite portion of the energy which is transferred from the supply mains to the service mains is transferred by virtue of the conductive connections through the armature windings of the converter.

The Synchroncus Converter

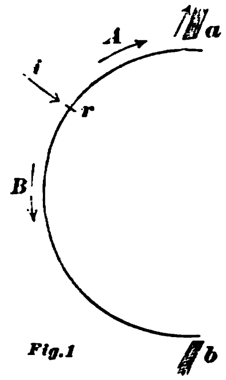

Fig.1

The Autotransformer

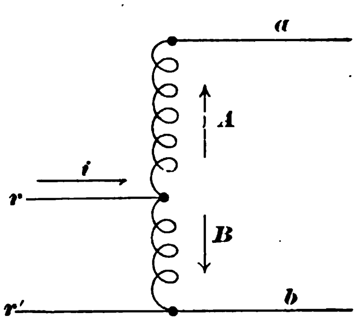

Fig.2

In the auto-transformer a definite portion of the energy which is transferred from the supply mains to the service mains is transferred by being inductively transformed from winding B, Fig. 2, which acts as a primary coil, to winding *A*, which acts as a secondary coil. In the synchronous converter a definite portion of the energy which is transferred from the supply mains to the service mains, is transferred by being inductively transformed from the portion *B*, Fig. 1, of the armature winding, which at the given instant acts as a motor, to the portion *A* of the armature winding, which at the given instant acts as a generator.

The object of this paper is to determine, of the total energy which flows through a synchronous converter, the fractional part which is conductively transferred from supply mains to service mains, and the fractional part which is inductively transformed. In case of the two-ring converter, the inductively transformed energy consists of two distinct parts, namely, (*a*) The energy which is transformed by simultaneous and balanced generator-motor action, and (*b*) The energy which is transformed by successive and unbalanced generator-motor action. These parts will be more fully discussed when we consider the problem of the two-ring converter.

3. THE MANY-RING CONVERTER.

Fig. 3 represents one side of a two-pole, many-ring converter. E is the electromotive force between the d.c. brushes a and b, I is the direct-current entering at a and leaving at b, i is the current in the armature wires, at a point on the armature which

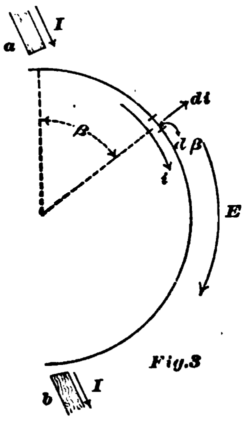

Fig.3

is at angular distance β from brush a, and di is the value of the alternating-current flowing out of all the collecting rings connected to commutator bars in the angular element $d\beta$ at the instant that these bars are at angular distance β from brush a. The arrows represent the directions in which the various electromotive forces and currents are considered as positive.

We shall assume here, as also in the discussion of the two-ring, the three-ring and the four-ring converters, that the converter receives alternating-currents at unity power-factor, that alternating electromotive forces and currents are harmonic, and that the losses of energy in the converter are negligible.

Before proceeding to the consideration of energy transformations, it is necessary to determine the distribution of current in the armature for given direct current output. From the above assumptions, we have:

$$di = -A\cos\beta\,.\,d\beta \qquad (1)$$

in which A is an undetermined constant. Integrating this equation we have

$$i = -A\sin\beta + K \qquad (2)$$

in which K is another undetermined constant. These constants A and K are determined by the following two conditions: 1st. The generator and motor activities are at each instant balanced in the many-ring converter and 2d, The alternating current input of power is equal to the direct current output of power. In order to formulate these two conditions it is necessary to find an expression for the generator (or motor) action in the element $d\beta$. Let de be the induced electromotive force in the element $d\beta$. Then it is easily shown on the basis of the above assumptions that

$$de = \tfrac{1}{2}E\sin\beta\,.\,d\beta \qquad (3)$$

Let dG be the generator action in watts (motor action if negative) in the element $d\beta$. Then $dG = i\,.\,de$, or

$$dG = -\frac{EA.}{2}\sin^2\beta.\,d\beta + \frac{EK.}{2}\,.\sin\beta\,.\,d\beta \qquad (4)$$

The first condition above mentioned requires that the integral of dG from $\beta = 0$ to $\beta = \pi$ shall be equal to zero. That is:

$$\int_0^\pi -A\sin^2\beta\,.\,d\beta + K\sin\beta\,.\,d\beta = 0 \qquad (5)$$

which gives

$$\frac{\pi A}{2} - 2K = 0 \qquad (6)$$

The alternating current intake of power in the half armature is

$$\tfrac{1}{2}E\int_0^\pi (1 - \cos\beta)\,di$$

and the direct current output of power in the half armature is

$$\tfrac{1}{2}EI$$

and these are equal, so that, using the value of di from equation (1), we have

$$I - \int_0^\pi A\cos^2\beta\,.\,d\beta - A\cos\beta\,.\,d\beta = 0 \qquad (7)$$

which gives

$$\frac{I-\pi A}{2}=0 \tag{8}$$

Equations (6) and (8) determine the values of A and K, giving

$$A=\frac{2I}{\pi} \tag{9}$$

$$K=\frac{I}{2} \tag{10}$$

Using these values of A and K in equation (2) we have

$$i=\frac{I}{2}-\frac{2I}{\pi}\sin\beta \tag{11}$$

It is worthy of note that the problem of the determination of armature currents in a synchronous converter is one which is properly based in every case on energy considerations, as in the above discussion.

We are now prepared to discuss the problem of energy transformations in the many-ring converter. Since the total generator action which is taking place at each instant in the many-ring converter is equal to the total motor action, therefore the inductively transformed power is equal to the total generator action (or to the total motor action). That is: the inductively transformed power, P, is equal to the integral of (4) over those portions of the armature where dG is positive. Now dG is positive where i is positive, since de is everywhere positive, and from equation (11) we find that i is *negative* from $\beta=0$ to $\beta=51^\circ.75$, *positive* from $\beta=51^\circ.75$ to $\beta \doteq 128^\circ.25$, and *negative* from $\beta=128^\circ.25$ to $\beta=180^\circ$. Therefore, attending to one-half of the armature and multiplying the result by two, we have:

$$P=EI\int_{\beta=51^\circ.75}^{\beta=128^\circ.25}-\frac{2}{\pi}\sin^2\beta\,.\,d\beta+\tfrac{1}{2}\sin\beta\,.\,d\beta \tag{12}$$

which gives

$$P=0.1153\,EI \tag{13}$$

That is, 11½ per cent. of the energy which flows through a many-ring converter is inductively transformed and 88½ per cent. is conductively transferred from the alternating current supply mains to the direct current service mains.

Remark:—The activities of the two-ring, three-ring and four-ring converters are much more complicated than those of the many-ring converter. The wide separation of the alternating current taps in the few-ring converter introduces pulsations in value of current and power in the various windings, as they pass a given point, so that in considering the internal actions of the few-ring converter, everything must be expressed as a function of time; and in the summation of generator and motor actions time integrations are involved.

4. The Two-Ring Converter.

Fig. 4 represents one side of the armature of a two-pole two-ring converter; r is one of the a.c. taps, a and b are the d.c. brushes, E is the electromotive force between d.c. brushes, I is the direct current flowing in at a and out at b, and i_a and i_b are the values of the currents in the armature parts as shown at instant t. The arrows show the directions in which the various electromotive forces and currents are considered as positive.

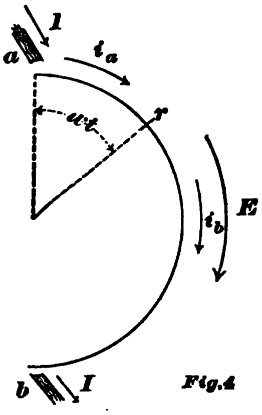

Fig.4

The algebraic expressions for i_a and i_b are determined fundamentally by the same consideration of energy relations as in case of the many-ring converter. These expressions are:

$$\left.\begin{aligned} i &= \tfrac{1}{2} I + I \cos \omega t \\ i_b &= \tfrac{1}{2} I - I \cos \omega t \end{aligned}\right\} \qquad (14)$$

Furthermore,

$$\left.\begin{array}{l}\text{e.m.f. between } a \text{ and } r = \tfrac{1}{2}E\,(1 - \cos\omega t)\\ \text{e.m.f. between } r \text{ and } b = \tfrac{1}{2}E\,(1 + \cos\omega t)\end{array}\right\} \qquad (15)$$

Let A be the generator action (motor action when negative), in watts between a and r; and let B be the generator action (motor action when negative), between r and b. Then

$$A = \tfrac{1}{2}EI\,(\tfrac{1}{2} + \tfrac{1}{2}\cos\omega t - \cos^2\omega t) \qquad (16)$$

$$B = \tfrac{1}{2}EI\,(\tfrac{1}{2} - \tfrac{1}{2}\cos\omega t - \cos^2\omega t) \qquad (17)$$

In case of the two-ring converter, the total generator action does not balance the total motor action at each instant and we must distinguish two parts in the inductively transformed power, namely: the power P which is transformed by simultaneous and balanced generator and motor action, and the power Q, which is first converted into kinetic energy as the armature is accelerated and afterwards converted back into electrical energy as the armature is retarded.

The power $P/2$ (the division by two is on account of our considering one-half only of the armature) is equal to the integral of A during the time that A is positive, B negative, and A numerically less than B; *plus* the integral of B during the time that B is positive, A negative and B numerically less than A; *minus* the integral of A during the time that A is negative, B positive, and A numerically less than B; *minus* the integral of B during the time that B is negative, A positive, and B numerically less than A,—these integrals being extended over half a cycle, and the final result divided by the duration of half a cycle. The value of P so found when divided by EI gives, of the total power which flows through the machine, the fractional part which is inductively transformed without passing through the intermediate stage of kinetic energy.

From equations (16) and (17) we find:

1. Generator action in ar is *less* than motor action in rb from $\omega t = 0$ to $\omega t = 45°$.

2 Generator action ar is greater than motor action rb from $\omega t = 45°$ to $\omega t = 60°$.

3. Generator action takes place in both ar and rb from $\omega t = 60°$ to $\omega t = 120°$.

4. Motor action in *a r* is *less* than generator action in *r b* from $\omega t = 120°$ to $\omega t = 135°$.

5. Motor action in *a r* is *greater* than generator action in *r b* from $\omega t = 135°$ to $\omega t = 180°$.

Therefore,

$$P = \frac{2}{\pi}\int_{0}^{45°} A \,.\, dx + \frac{2}{\pi}\int_{135°}^{180°} B \,.\, dx - \frac{2}{\pi}\int_{120°}^{135°} A \,.\, dx - \frac{2}{\pi}\int_{45°}^{60°} B \,.\, dx \quad (18)$$

in which x is written for ωt.

The numerical evaluation of the integrals in equation (18) gives:

$$\frac{P}{E I} = 0.09517 \quad (19)$$

That is; 9½ percent of the total energy which flows through a two-ring converter is inductively transformed by simultaneous and balanced generator and motor action.

The power $Q/2$ (division by two is on account of considering one-half only of the armature) is found by taking the integral of $A+B$ during the time that this sum is positive, namely; from $\omega t = 45°$ to $\omega t = 135°$, and dividing the result by the duration of half a cycle. This gives

$$\frac{Q}{E I} = \frac{1}{\pi}\int_{45°}^{135°} (1 - 2\cos^2 x)\, d x = 0.3183 \quad (20)$$

That is; 31.8 percent of the energy which flows through a two-ring converter is inductively transformed by successive and unbalanced generator and motor action.

From the above results, it follows that 58.65 percent of the energy which flows through a two-ring converter is transferred from the alternating-current supply mains to the direct-current service mains by virtue of the conductive connections through the converter armature.

5. THE THREE-RING CONVERTER.

Fig. 5 shows one side of the armature of a two-pole three-ring converter:—r' and r'' are two of the three a.c. taps; *a* and *b* are the d.c. brushes; i_a i . and i_c are the values of the currents in the armature parts, as shown at instant t; E is the electromotive force between the d.c. brushes. and I is the steady current flowing in at a and out at b. The arrows show the direction in which the various quantities are considered positive.

The algebraic expressions for i_a, i_b and i_c are

$$\left.\begin{aligned} i_a &= \frac{I}{2} - \frac{4I}{3\sqrt{3}} \cos(\omega t - 150^\circ) \\ i_b &= \frac{I}{2} - \frac{4I}{3\sqrt{3}} \cos(\omega t - 30^\circ) \\ i_c &= \frac{I}{2} - \frac{4I}{3\sqrt{3}} \cos(\omega t + 90^\circ) \end{aligned}\right\} \qquad (21)$$

For present purposes, we need consider only the generator and motor actions which occur in the three armature parts $a\,r'$,

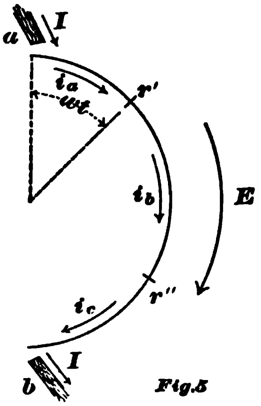

Fig.5

$r'r''$ and $r''b$, during one-third of a cycle, namely, from $\omega t = 0$ to $\omega t = 120^\circ$. The integral of all the generator actions in these armature parts during this third of a cycle divided by the duration of the third of a cycle, gives one-half of the inductively transformed power P.

The electromotive forces involved are as follows:

$$\text{e.m.f. between } a \text{ and } r' = \tfrac{1}{2} E\,(1 - \cos\omega t) \qquad (22)$$

$$\text{e.m.f. between } r' \text{ and } r'' = \frac{\sqrt{3}\,E}{2} \cos(\omega t - 30^\circ) \qquad (23)$$

This equation is available only from $\omega t = 0$ to $\omega t = 60^\circ$ since at the instant $\omega t = 60^\circ$, r'' coincides with b and after this instant a portion of the section $r' r''$ is in the half armature which is out of consideration.

$$\text{e.m.f. between } r' \text{ and } b = \tfrac{1}{2} E\,(1+\cos \omega t) \tag{24}$$

This equation is used only during the interval from $\omega t = 60^\circ$ to $\omega t = 120^\circ$.

$$\text{e.m.f. between } r'' \text{ and } b = \tfrac{1}{2} E \left[1 - \cos(\omega t - 60^\circ) \right] \tag{25}$$

Let A, B', B'' and C be the generator actions (motor actions when negative) in the armature parts $a\,r'$, $r'\,r''$, $r'\,b$ and $r''\,b$ respectively at instant t. Then we have:

$$A = \tfrac{1}{2} E\,(1 - \cos \omega t)\,.\,i_a \tag{26}$$

$$B' = \frac{\sqrt{3}\,E}{2}\,.\cos(\omega t - 30^\circ)\,.\,i_b \tag{27}$$

$$B'' = \tfrac{1}{2} E\,(1 + \cos \omega t)\,.\,i_b \tag{28}$$

$$C = \tfrac{1}{2} E \left[1 - \cos(\omega t - 60^\circ) \right].\,i_c \tag{29}$$

Equation (27) applies from $\omega t = 0$ to $\omega t = 60^\circ$, and equation (28) applies from $\omega t = 60^\circ$ to $\omega t = 120^\circ$.

From equations (26) to (29) we find:

A is *positive* from $\omega t = 0$ to $\omega t = 100^\circ.5$
A is *negative* from $\omega t = 100^\circ.5$ to $\omega t = 120^\circ$
B' is *negative* all the time during which it applies
B'' is *negative* from $\omega t = 60^\circ$ to $\omega t = 79^\circ.5$
B'' is *positive* from $\omega t = 79.^\circ5$ to $\omega t = 120^\circ$.
C is *positive* from $\omega t = 0$ to $\omega t = 60^\circ$

Therefore

$$P = \frac{3}{\pi}\int_{0}^{100^\circ.5} A\,.\,dx + \frac{3}{\pi}\int_{79^\circ.5}^{120^\circ} B''\,.\,dx + \frac{3}{\pi}\int_{0}^{60^\circ} C\,.\,dx \tag{30}$$

Substituting the values of i_a, i_b and i_c from equation (21) in equations (26), (28) and (29), and the resulting values of A, B'' and C in equation (30) and integrating, we find:

$$P = 0.2358\,E\,I \tag{31}$$

That is, 23.6 percent of the energy which flows through a three-ring converter is inductively transformed by simultaneous and balanced generator and motor action, and the remainder, 76.4 percent is transferred from the supply mains to the service mains by virtue of the conductive connections through the converter armature.

6. The Four-ring Converter.

Fig. 6 shows one side of the armature of a two-pole four-ring converter; r' and r'' are two of the a.c. taps; a and b the d.c. brushes; i_a, i_b and i_c are the values of the currents in the armature parts, as shown at the instant t; E is the electromotive force between the d.c. brushes, and I is the current flowing in at a and out at b. The arrows show the direction in which the various quantities are considered as positive.

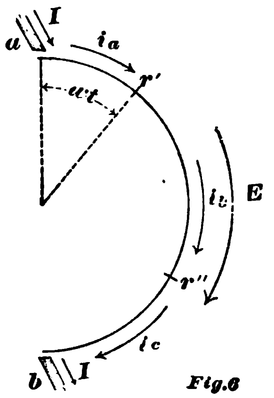

Fig.6

The algebraic expressions for i_a, i_b and i_c are as follows:

$$\left.\begin{aligned} i_a &= \frac{I}{2} - \frac{I}{\sqrt{2}} \cdot \cos(\omega t - 135^\circ) \\ i_b &= \frac{I}{2} - \frac{I}{\sqrt{2}} \cdot \cos(\omega t - 45^\circ) \\ i_c &= \frac{I}{2} - \frac{I}{\sqrt{2}} \cdot \cos(\omega t + 45^\circ) \end{aligned}\right\} \tag{32}$$

Furthermore, e.m.f. between a and $r' = \frac{1}{2} E (1 - \cos \omega t)$ (33)

e.m.f. between r' and $r'' = E \cos (\omega t - 45^\circ)$ (34)

e.m.f. between r'' and $b = \frac{1}{2} E (1 - \sin \omega t)$ (35)

In the present case we need only consider the generator and motor actions which occur in the half armature during a quarter of a cycle, namely, from $\omega t = 0$ to $\omega t = 90°$. The integral of the generator actions in the three armature parts $a\,r'$, $r'\,r''$, and $r''\,b$ during the specified quarter of a cycle divided by the duration of a quarter cycle, gives one-half of the inductively transformed power P.

Let A, B and C be the generator actions (motor actions when negative) in the armature parts $a\,r'$, $r'\,r''$, and $r''\,b$ respectively at instant t. Then we have:

$$A = \tfrac{1}{2} E\,(1 - \cos \omega t)\,.\,i_a \tag{36}$$

$$B = \frac{E}{\sqrt{2}}.\cos\,(\omega t - 45°)\,.\,i_b \tag{37}$$

$$C = \tfrac{1}{2} E\,(1 - \sin \omega t)\,.\,i_c \tag{38}$$

From these equations we find

A is *positive* from $\omega t = 0$ to $\omega t = 90°$.

B is *negative* from $\omega t = 0$ to $\omega t = 90°$.

C is *positive* from $\omega t = 0$ to $\omega t = 90°$.

Therefore,

$$P = \frac{4}{\pi}\int_0^{90°} A\,.\,dx + \frac{4}{\pi}\int_0^{90°} C\,.\,dx \tag{39}$$

in which x is written for ωt.

Substituting the values of i_a and i_c from equations (32) in equations (36) and (38) and substituting the resulting values of A and C in equation (39) and integrating, we find

$$P = 0.1285\,E\,I \tag{40}$$

That is, 12.9 percent of the energy which flows through a four-ring converter is inductively transformed by simultaneous and balanced generator and motor action, and 87.1 percent is con-conductively transferred from the supply mains to the service mains

7. SUMMARY.

Energy Transformations in the Synchronous Converter.

Number of rings.	Percent of energy transformed by successive and unbalanced generator and motor action.	Percent of energy transformed by simultaneous and balanced generator and motor action.	Percent of energy conductively transferred.
2	31.83	9.517	58.65
3	0	23.58	76.42
4	0	12.85	87.15
Infinite	0	11.53	88.47

The calculation of these results demanded a great deal of painstaking computation; in fact, an amount which is very unusual in problems of this kind. These computations were done chiefly by Professor Wm. Esty, to whom the author wishes to express his thanks.

8. ARMATURE REACTION OF THE MANY-RING CONVERTER AND ITS EFFECT IN DISTORTING THE ELECTROMOTIVE FORCE CURVE OF THE MACHINE.

Consider the distribution of the magnetic field in the gap-space when the load on the converter is zero, and consider the distribution of field in the gap-space when the machine is delivering an amount of direct-current I. Let f be the difference in value of these two fields at a point at angular distance β from the direct current brush a, Fig. 3. Let $d\,f$ be the variation of f in the element of angle $d\,\beta$. Let l be the magnetic length of the gap-space in centimetres, n the number of armature conductors per centimetre of armature circumference, and let i be the current in the armature conductors at the element $d\,\beta$. Then from the fundamental relation between magnetomotive force and current-turns, we have:

$$l.df = \frac{4\pi.}{10} ni.d\beta$$

or

$$df = \frac{4\pi n i}{10 l} \cdot d\beta \tag{41}$$

Substituting the value of i from equation (11) we have

$$df = \frac{2\pi n I}{10 l} \cdot d\beta - \frac{8 n I}{10 l} \cdot \sin\beta \; d\beta \tag{42}$$

Integrating

$$f = \frac{2\pi n I \beta}{10 l} + \frac{8 n I \cos\beta}{10 l} + C \tag{43}$$

In which C is a constant to be determined. By symmetry of winding and symmetry of distribution of current in two halves of armature, the value of f when $\beta = 0$ must be equal and opposite to the value of f, when $\beta = \pi$. Applying this condition to equation (43) we find,

$$C = -\frac{\pi^2 n I}{10 l} \tag{44}$$

which, substituted in equation (43) gives:

$$f = \frac{n I}{10 l}(2 \pi\beta + 8 \cos \beta - \pi^2) \tag{45}$$

This equation holds good on one side only of the armature. For expressing the values of f on the other side of the armature, the angle β must be measured from the brush b, Fig. 3.

If the electromotive force curve of the converter is determined by using an auxiliary concentrated winding of T turns of wire, then the amount by which the ordinate of the full load electromotive force curve exceeds the corresponding ordinate of the zero load electromotive force curve at the point β in volts is

$$e' = \frac{2 L T v n I}{l} \cdot (2 \pi \beta + 8 \cos \beta - \pi^2) \div 10^9 \tag{46}$$

in which L is the length of the armature in centimetres and v is the peripheral velocity of the armature in centimetres per second.

If it is desired to cut away a layer of thickness x from the pole face, so as to compensate for the armature reaction at full load, causing the machine to give the same electromotive force curve at full load as it previously did at zero load, this may be done and the thickness x is a function of β. In fact

$$x = \frac{f}{B} . l$$

in which B is the field intensity in the gap-space at zero load. Therefore

$$x = \frac{n I}{10 B} (2 \pi \beta + 8 \cos \beta - \pi^2) \tag{47}$$

9. THE CRITERION OF REALITY OF THE COMPONENT PARTS INTO WHICH A PHYSICAL AGGREGATE IS RESOLVED BY MATHEMATICAL ANALYSIS.

In the derivation of an algebraic expression for a determinate physical variable, two sets of conditions in general apply:—1. The condition or conditions which must be satisfied always and everywhere; that is, throughout the interval of time and throughout the region of space over which the expression is to apply. These conditions are in most cases the requirements of the principle of the conservation of energy. 2*a*, The condition or conditions which must be satisfied at the boundary of the region and 2*b*, The condition or conditions which must be satisfied at the beginning of the time. Conditions 1 we will call *persistent* conditions. Conditions 2*a* may be *persistent*.

Consider as an example the problem of the vibration of an elastic string. The energy of the string is repeatedly transformed from kinetic to potential and back again, and the constancy of total energy is expressed by the well-known differential equation:

$$\frac{d^2y}{dt^2} = -v^2\frac{d^2y}{dx^2} \tag{a}$$

which must be always and everywhere satisfied.

At the ends of the string we have the persistent conditions,

$$y = 0 \text{ when} \left\{ \begin{matrix} x = 0 \\ \text{or} \\ x = l \end{matrix} \right\} \tag{b}$$

Any motion of the string is possible which satisfies these persistent conditions. Suppose that at the instant $t = 0$, the string is distorted into the shape represented by the equation,

$$y = f(x) \tag{c}$$

The solution of the problem is

$$y = A \sin\frac{2\pi x}{l} + B \sin\frac{4\pi x}{l} + C \sin\frac{6\pi x}{l} + \dots\dots \tag{d}$$

The various terms in this equation represent the component parts into which the actual motion of the string is resolved by the mathematical analysis of the problem. Each of these component parts satisfies all the persistent conditions of the problem and may therefore actually exist by itself, and there is no reason why we should not look upon each of these parts as real. *In general, the component parts into which a physical aggregate is resolved by* *mathematical analysis may be considered as real when each of these parts satisfies all of the persistent conditions of the problem and may exist alone.*

Consider, as another example, the problem of the decay of current in an inductive circuit when the driving electromotive force is removed. Placing the rate of disappearance of electrokinetic energy equal to the rate of generation of heat in the circuit, we have as a result the differential equation:

$$R i + L \frac{d i}{d t} = 0 \qquad (e)$$

which equation must be always satisfied. Furthermore, at the beginning, the current has a certain prescribed value I. That is:

$$i = I \text{ when } t = 0 \qquad (f)$$

The solution of this problem is

$$i = I \left(1 - t + \frac{t^2}{1 \cdot 2} - \frac{t^3}{1 \cdot 2 \cdot 3} + \frac{t^4}{1 \cdot 2 \cdot 3 \cdot 4} - \cdots\cdots\right) \qquad (g)$$

in which R/L has for brevity been placed equal to unity. The various terms in equation (g) represent component parts of the current i: these parts do not satisfy the conditions of the problem; they cannot exist alone under the conditions of the problem, and therefore these parts cannot be looked upon as physically *real. In general, the component parts into which a physical aggregate is resolved by mathematical analysis cannot be considered as real when they do not separately satisfy the persistent conditions of the problem and when these parts cannot exist individually and separately under the conditions of the problem.*

Consider the case of the polyphase synchronous converter after it is in full operation. The persistent condition is equality of inflow and outflow of electrical energy and constancy of kinetic energy of armature. The problem of the determination of armature current under these conditions leads to expressions [see equations (11), (14), (21) and (32], which involve two terms. That is: the armature current is resolved into two parts and these parts correspond to inflowing alternating current and outflowing direct current respectively. This correspondence strongly suggests the physical reality of these two parts of the armature current; but as a matter of fact neither part of the armature current satisfies the conditions of the problem, neither part can exist alone under the conditions of the problem and therefore these parts are mathematical fictions and not physical realities.

DISCUSSION.

SAMUEL SHELDON:—I had the good fortune to see this paper before it was presented here, being chairman of the Committee on Papers, and therefore I have the advantage of the rest of the members present. I think that the great amount of work which has been put upon the paper ought to be recognized by the membership.

The conclusion which Professor Franklin draws on the last page of this paper, is as follows:

"The armature current is resolved into two parts, and these parts correspond to inflowing alternating current and outflowing direct current respectively. This correspondence strongly suggests the physical reality of these two parts of the armature current; but as a matter of fact neither part of the armature current satisfies the conditions of the problem, neither part can exist alone under the conditions of the problem, and therefore, these parts are mathematical fictions and not physical realities."

This agrees perfectly with my understanding of the case, but I have not come to this conclusion by the application of his criterion. It seems to me that in any portion of a conductor that is supplied with e.m.f.'s of any sort there never can be but one current, and it is always in phase with itself. Now, I know that it is very convenient, when a wave is distorted because of hysteresis or anything else, to divide the current into two parts which are called wattless and watted, these components differing in phase by 90 degrees, but a physical conception of the flow of current in a circuit does not permit of such a division of the current. Consider an armature inductor of a converter. If any current at all flows in it, it must flow in either one direction or in the other. Now, if the current be flowing in the same direction as the e. m. f., which is being induced in that inductor, then that particular inductor is acting as a generator. If it be flowing in an opposite direction, then that particular inductor is operating as a motor. In the armature of any synchronous-converter motor and generator, actions exist separately at different parts of the armature. They may be balanced, one being equal to the other but opposite in direction, but the motor activity is transmitted mechanically through the structure of the armature. In a three-phase converter it is present at all times, and the armature rotation is synchronous with the three-phase currents which produce it. Therefore, I cannot see how Professor Franklin's conclusion can be made to correspond with the statement on page 876, at the close of paragraph 1, which says:

"I give in a subsequent section of this paper a statement of the criterion which enables one to judge of the physical reality or unreality of the component parts into which a physical aggregate is resolved by mathematical analysis, and it suffices here to state that this criterion shows the physical unreality of synchronous motor activity and direct-current generator activity as component parts of the activity of the synchronous converter."

Professor Franklin has called attention to the fact that this subject is a difficult one to handle by this method. This is evident, and I think the subject can be treated in a much more satisfactory manner in the case of an actual converter, as well as of a theoretical converter, by making use of a series of current-time curves plotted one above the other, on abscissas which represent times or angular positions of the armature core. Considering a bipolar machine, the shape of this current-time curve is to be derived by combining the direct current rectangular curve which changes its direction as the coil under consideration passes under a brush, with the alternating current curve. If the latter be assumed to be sinusoidal, as has been assumed in this paper, it will have a maximum value of twice the direct current output divided by n times the sine of π divided by n, where n represents the number of phases under consideration or the number of taps or slip-rings. These two curves are to be combined at a phase difference depending upon the angular position of the coil under consideration relative to the coil which is midway between two successive taps, and upon the power-factor. In an ideal converter at unity power-factor, the alternating current in all coils between two successive taps has a maximum value when the middle coil is under the center of a pole. This method may appear difficult, but for an actual converter it is not at all difficult. The drawing of the curves merely involves the use of a T-square and a templet which corresponds to the a. c. wave form. Draw one above the other, and on the same abscissas, as many current-time curves as there are coils between two alternating current taps. Then, by placing the edge of a ruler vertically over any abscissa, the instantaneous values of the currents in that particular phase for any or all coils at that time can be read off, and for any other phase the currents at the same time can be taken from the same set of curves by displacement of the ruler by a proper number of degrees. I think that this method has some advantages over that of Professor Franklin. He has to assume that the e.m.f., which is induced in the inductors; that is, the distribution of flux, is cosinusoidal. In using the graphical method, any distribution of flux may be considered, and it can be used for determining the power in any inductor in any position. Furthermore, the operation losses which are neglected in the analytical treatment can be considered. I have employed the graphic method just mentioned and have gone through the calculations for the three-phase converter, and I obtain practically the same results as Professor Franklin has found here; namely, that about 23 percent of the energy is transferred by simultaneous and balanced generator and motor action. The coils which are acting as generators are, however, distinct from those which are acting as motors at the same instant of time.

[Communicated after Adjournment by Samuel Sheldon.]

From calculations, which have been carefully gone over since the presentation of Professor Franklin's paper, and which I am firmly convinced are correct, the value of the amount of energy transformed by simultaneous and balanced generator and motor action, in the case of a 4-ring converter, is about 18 percent and not 12.85 percent, as given in the paper. Further calculations confirm the values given in the paper for the single-phase and the three-phase converter.

It seems to me unfortunate that the auto-transformer should have been chosen and used as analagous in operation to the converter, especially in the effort to draw any conclusions as to the physical reality or unreality of motor and generator actions. The rotating part of the synchronous converter, through its kinetic energy, acts as a medium of conversion between the electrical energies of input and output. The core of the auto-transformer, through the potential energy of its magnetic flux, performs a similar service. Therefore the presence of motor activity is to be looked for and expected in the converter, and its absence can be postulated in the case of the auto-transformer. This follows also from a consideration of the field magnets, which are present in the case of the converter but are wanting in the auto-transformer. Furthermore, the inductive relations between the different coils on the core of the auto-transformer are at the basis of its operation and therefore the self and mutual inductances are made comparatively large, while the inductive relations between the coils on the core of the converter armature are insignificant factors in its operation and, therefore, the self and mutual inductances are intentionally made small. In fact, the differences between the constructions and the methods of operation of the two machines are many and fundamental.
phase synchronous converter, states as the "persistent condition"

Professor Franklin, in applying his criterion of reality to the poly-
the "equality of inflow and outflow of electrical energy and constancy of kinetic energy of armature." He erroneously includes, in his treatment equation (14), which represents, by the two terms of its second member, the two components of the armature current in a 2-ring converter. In this machine there is an inequality between inflowing and outflowing electrical energy and there is not a constancy of kinetic energy of armature. The "persistent condition" may be better stated, in that both single and polyphase converters are included, as follows: *A constant difference between the inflow of electrical energy and the kinetic energy of the synchronous converter armature which is equal to the constant outflow of energy.*

Professor Franklin states in substance that the component parts of an equation do not stand for physical realities unless they separately hold for all the "persistent conditions" of the problem, and may exist alone all the time under said conditions. He concludes that the component parts of the equations representing motor and generator actions in a converter cannot exist separaately all the time and that there are, therefore, no physically real motor and generator actions. By the same token his "Criterion" cannot be valid unless good for every instant of the persistent conditions present in a converter. Now, in a 2-ring converter when the a.c. taps are under the d.c. brushes the exact conditions are present within the machine that are found in an ordinary continuous-current motor, and no others. From this it is evident that physically real motor action must be the action that is going on at that time. After a revolution of the armature through 90°, the exact conditions of an ordinary continuous-current generator are present, and no others. At that time there must be physically real generator action going on. All of this is contrary to the conclusions derived by Professor Franklin from the use of his " Criterion," and they suggest that its use fails to give a convincing consciousness of the physical reality or unreality of the actions which can be represented by the component parts of an equation for a physical aggregate.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 29, 1903.

COMMERCIAL ALTERNATOR DESIGN.

BY W. L. WATERS.

Deals with the chief elements entering into the design of alternators which affect the cost of the machine and gives a short account of the general tendencies in alternator design. Questions dealt with from the practical rather than from the theoretical standpoint.

The design of alternators has been treated times without number, but usually the commercial element in the design, *i.e.*, the relation of factory cost to selling price, has been left out. An engineer has been defined as a man who can do for one dollar what any fool can do for two, and this definition applies fairly well in connection with the design of machines. The man who can design the cheaper machine to satisfy a given specification is the better designer.

Speaking generally, there is no type of alternator that will compare with the internal revolving-field type with each pole carrying a separate field-coil of edge-on copper strap. The revolving-armature type is cheaper for high frequencies and low voltages. The inductor type is good for small 60-cycle high-speed machines, and the disk alternator without iron in the armature is an excellent machine for high frequencies. But these machines, though good enough in their own limited field, do not compare with the revolving-field type for general all-around work.

The revolving-field alternator took its present form about 1892 when Mr. C. E. L. Brown designed machines which were practically modern machines, while in 1893 Mr. S. Z. de Ferranti installed some 210 kw alternators at Portsmouth, England, which were of similar design to those of Brown[1]. Before this date

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[1] I understand from Mr. Brown that the firm of Brown, Boveri et Cie, deserves to some extent the credit for the design of the Portsmouth alternators, though Mr. Ferranti was the first to use edge-on copper strap for field magnets.

machines of this type were of a clumsy amateur design, and their performance was, generally speaking, very poor. And strangely enough, these two engineers after bringing out a first-class design, apparently abandoned further development, and their machines to-day are almost identical with their machines of ten years ago.

It has taken the different manufacturing concerns a long time to recognize the superiority of the Brown and Ferranti type for standard work, and it is practically only during the last three or four years that this type has been generally adopted. The result is that except for a few minor details, the construction of these machines has been improved very little since they were first introduced, while the excellence, from a commercial point of view, of the electrical design of Brown's early machines seems hardly recognized even yet by some engineers; and we have alternators on the market which are for a given performance decidedly more expensive than Brown's machines of ten years ago.

The armature frame in the Brown type of machine was simply a skeleton cast-iron frame for clamping the laminations together, and was full of large ventilating holes, while the ends of the armature coils stood out from the laminations quite free and exposed to the full windage of the magnet-wheel. The numerous holes gave excellent cooling effect, but they cut all the strength and stiffness out of the frame, and the armature had to be stiffened by a series of tie-rods or struts. This construction which saves material at the expense of labor, has become standard with German and Swiss firms, though on account of its unsightly appearance it has never found favor in this country. This type of alternator, shown in Fig. 1, has retained practically its original form up to the present and developments that have taken place have been mostly in the Ferranti type.

American and English engineers have followed the Ferranti type shown in Fig. 2, and made the armature frame stiff enough to stand without bracing. The trouble with this construction was originally the poor ventilation of the armature. Ventilating spaces were either not used or if they were, there was no proper circulation of air through them. The end connections on the armature winding or the ends of the coils, were packed tight together, or were closed in by cover-plates permitting no ventilation at all. Thus, the armature winding was usually the hottest part of the machine. So even allowing temperature rises of 45° C., the machines would not give anything like the rating they should, simply on account of the poor ventilation. And because, when American and English engineers took up the revolving-field type of alternator, the badly ventilated Ferranti type was adopted and the great importance of ventilation was not recognized, the development of alternator design in America and England has been comparatively slow.

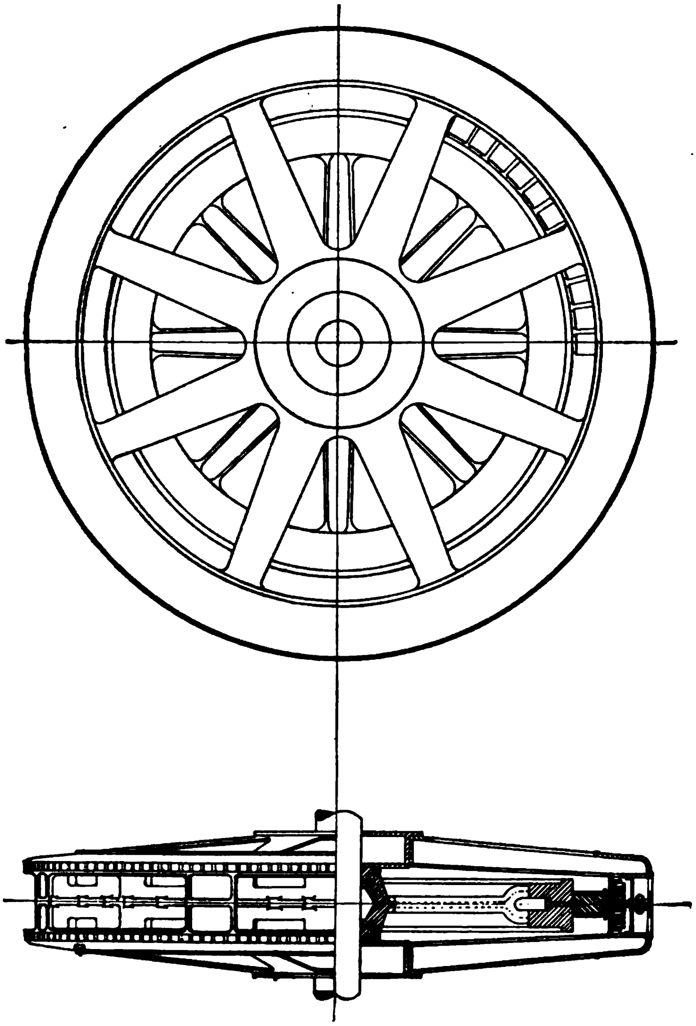


FIG. 1.

The improvement in ventilation which has recently taken place in this type of alternator is really the greatest forward step that has been made and it has given the designer immense help in increasing the output of his machines.

Fig. 3 shows an old, badly-ventilated armature, while Figs. 4 and 8*a* show a more up-to-date well-ventilated machine. In Figs. 4 and 8*a* it will be seen that where the ends of the armature coils cross one another they are separated by an air-space and that the end covers are full of ventilating holes, so that there is a circulation of air all around the coils, and the armature winding instead of being the hottest part of the machine, becomes the coolest. The armature core is well provided with vent spaces both at the

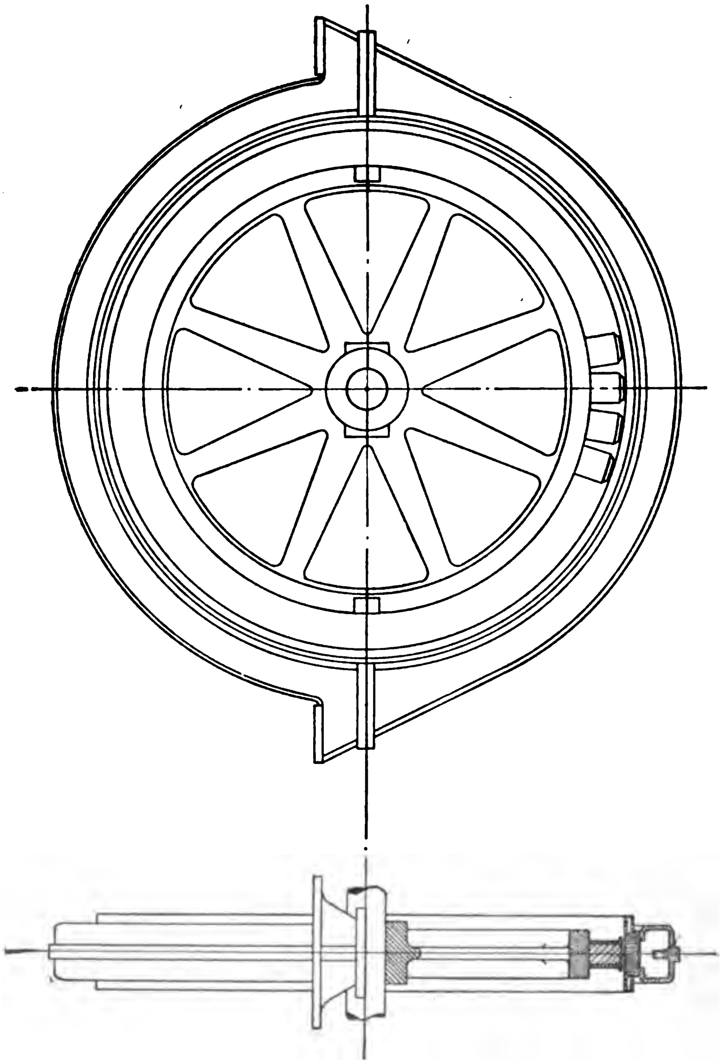


FIG. 2.

center and at the ends, and the air passing through these vents is free to escape at the back of the core. This type of armature coil has the additional advantages that if lightning gets into the machine or a coil is burnt out, the damage is confined to one coil and we do not have half-a-dozen burnt out as usually happens. Also, all the coils on the armature are alike and made on the same former.

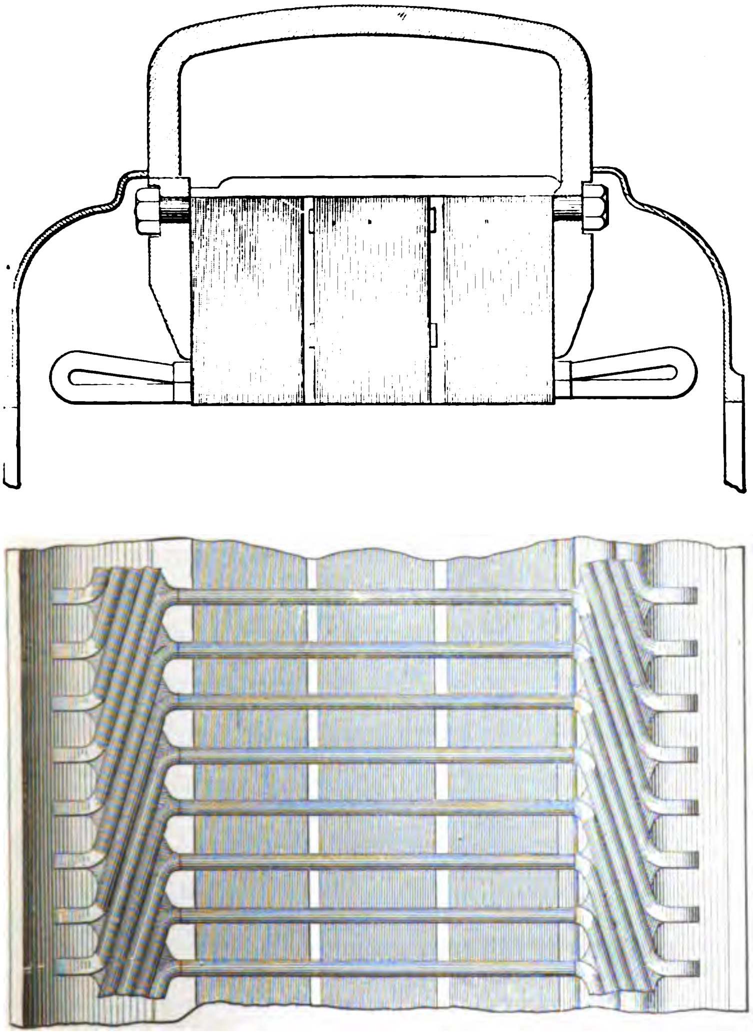


Fig 3

The difference in the cooling effect between these different types of machines may not seem much on paper, but it means all the difference between a temperature rise of 45° and one of 25° on actual test. It means that we need only take into consideration efficiency and regulation in designing a machine, knowing well that if these are all right we can guarantee a temperature rise of 25°, even on low-speed machines.

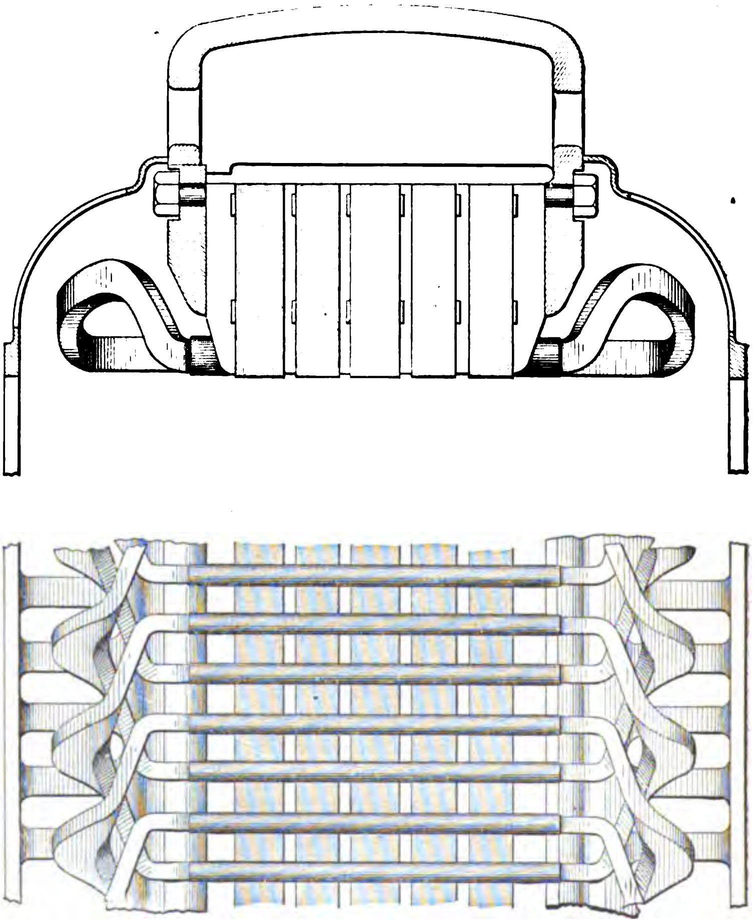


Fig. 4.

When designing any machine we have the choice of taking a large diameter and making the machine short, or of taking a small diameter and making the machine long. The difference in the cooling effect between these two is obvious from Figs. 5 and 6. In Fig. 5 the machine is small in diameter and long, the poles are crowded together and the winding packed in. All the heat from the field-coils has to be got rid of from the small exposed surface at the ends of the coils. In Fig. 6 the machine is large in diameter and short, and practically the whole surface of the field-coil is available for cooling. In addition, the field-coils being separated more from one another and the peripheral speed being higher, the cooling effect on the armature is much greater.

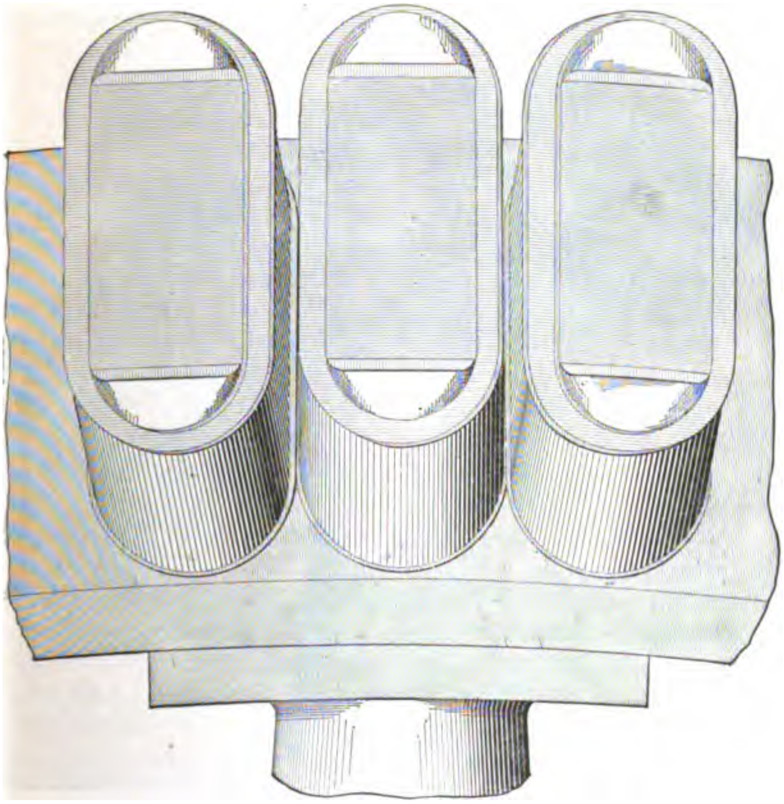


FIG. 5.

The machine in Fig. 6 being built on a large diameter will require heavier castings and present greater difficulties in handling, but the fact that the designer need not trouble about the temperature rise gives him so much more latitude, that he will easily offset this slight extra expense by a cheaper design generally and will in addition have a much cooler machine.

The difference in cooling between an alternator with armature and magnets as shown in Figs. 3 and 5 and one with armature and magnets as shown in Figs. 4 and 6 is so perfectly plain, that it is quite surprising to find the poorly-ventilated type still on the market. The only inference to be drawn is that the firms building them have no tools capable of handling the larger diameter castings.

Coming to the electrical part of the design, the first thing to be decided is the specification to which the machine is to be built. The firm with which I am connected, having only recently taken up this work, has adopted for standard practice:

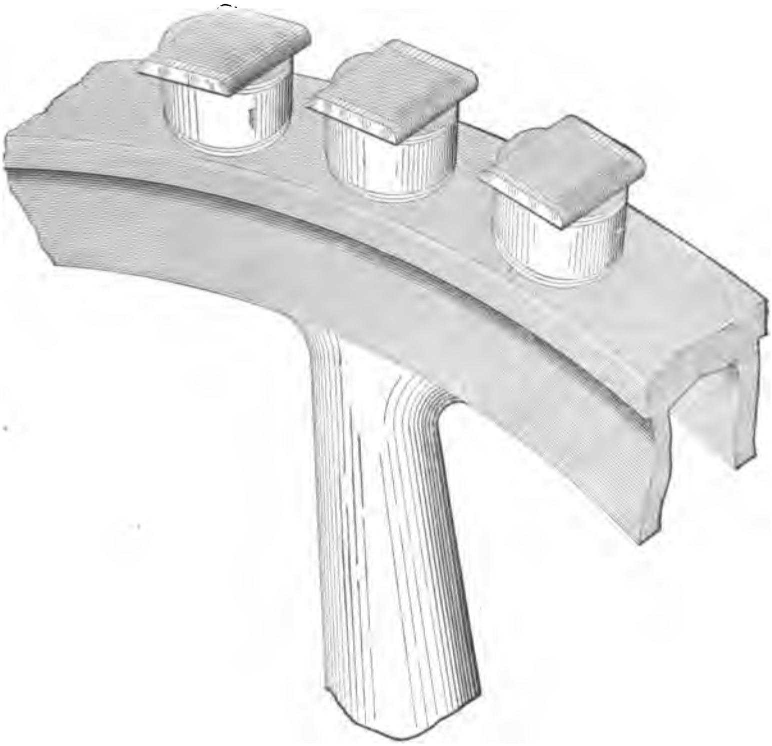


FIG. 6.

A temperature rise of 30° C. on a continuous full-load run;

A temperature rise of 45° C. on 50 percent over-load for two hours;

A regulation of 5 to 7 percent according to the size of the machine;

And gives a guarantee that all machines will without damage give continuously 50 percent current over-load at $PF = 0$.

Given our specifications, we have next to decide what diameter we shall make the machine? What magnetic densities to take in the iron? What current density in the conductors? What percentage of the pole pitch shall the pole face be? What air-gap? Of course, these questions can only be answered off-hand as the results of experience. But generally speaking we can, after a few trials, get down to the best design. We have only to consider the efficiency, the regulation and the cost, as with a good design the temperature need not be considered.

The efficiency of a machine within ordinary limits practically depends on the magnetic densities in the iron and the current densities in the copper. The higher the densities the cheaper and the less efficient the machine. The copper-loss in the armature is usually between 1 and 2 percent. Apart from the efficiency this is decided by the regulation, because when you are only allowing 5 to 7 percent drop on $P F = 1$, you cannot well have more than 2 percent of this as $I R$ drop. This means that in low-speed machines with a large number of poles, the current density in the armature is very low, while in high-speed machines with few poles the current density can be much higher. In practice it varies from 1200 to 3000 amperes per square inch. The iron densities do not vary much in standard machines, as the most economical densities are very fairly constant and independent of the speed, and any attempt to get higher efficiencies by decreased iron densities is likely to run up the cost very fast.

The best ratio of pole face to pole pitch is largely a matter of opinion. If it is large, say 70 percent, then the e.m.f. coefficient (the Kapp coefficient) is reduced, and the total flux of the machine increased and hence the magnets made heavier. On the other hand we have more teeth to carry the flux so that for a given tooth-density the machine is shorter. But the armature core-plates are correspondingly deeper, so that the only saving is a slight decrease in the length of mean turn of the armature winding.

The larger the percentage of pole face to pole pitch the greater the magnetic leakage, and to a certain extent the less the synchronizing power of the alternator. So that there is little to be gained by much variation of this ratio, and it seems advantageous to keep it low, say between 55 and 65 percent.

The air-gap is decided by the regulation of the machine. An immense amount has been written on various theoretical methods of calculating the regulation of alternators, but broadly speaking the regulation depends on the ratio of the ampere-turns on the armature to the ampere-turns for the air-gap.

In an alternator the armature conductors are cut by magnetic lines due to the armature current *i.e.*, the armature self-induction line, and by magnetic lines due to the magnet current. But the self-induction of the armature varies with the value of the current in the armature and magnets, and with the relative position of the armature and magnets. And the useful lines due to the magnets vary with the current in the armature and field on account of the permeability of the iron and the magnetic leakage. So it is obvious that the conditions to be taken into account are so complicated that it is quite impossible to treat them theoretically, without making so many assumptions that the results even when obtained cannot be directly applied. What a designer has to do, is to work through theoretically a few simple special cases himself and then the results will give him an idea on what lines to work, and by means of experimenting on a number of machines he gets an empirical method for calculating the regulation. Afterwards as he gets more and more experience with alternators, he introduces further refinements, and taking the regulation curves obtained by those empirical methods he corrects them a little by eye.

Speaking generally from a designer's point of view, an alternator should be figured out for a certain regulation on a low power-factor, say $P\,F = 0$. For, if the machine is satisfactory for low power-factors it will be satisfactory, for $P\,F = 1$, while the converse is not true. Other things being equal, the larger the air-gap the better the regulation on the low power-factors. But the leakage-coefficient of the machine is an important factor, and this increases with the air-gap. The leakage-coefficient is, of course, taken into account in drawing the no-load saturation curve—but we have to remember that on full load of low power-factor the leakage-coefficient is much increased—the leakage is often doubled—on account of the extra ampere-turns required on the magnets to overcome the back ampere-turns on the armature. And if the leakage-coefficient is already high and if the density in the magnet iron is also high, we run a considerable risk of having the saturation curve bending over so fast that we cannot get our volts at all on loads of a low power-factor. It was just this trouble that made inductor machines fall out of use for low power-factor loads, as they are particularly sensitive to leakage and are always worked at high densities. Speaking generally, if the no-load leakage-coefficient of a machine is over 1.30, and if the density in the magnets is over 100,000 lines per sq. in., the designer has to be very careful or he will get into trouble.

The regulation on noninductive loads is not affected by the length of the air-gap to the same extent as the regulation on low power-factors. So machines which are intended only for lighting or synchronous converter work can usually be economically designed with a smaller air-gap, and hence smaller leakage, than machines for motor work.

In Europe, practically every alternator sold has to run motors so that the regulation either for $P\,F = .8$ or for $P\,F = 0$, has to be guaranteed. In this country, on account of the patent situation, induction motors are used only to a limited extent. As a result of this it has become standard practice to sell machines on a regulation guarantee for non-inductive, rather than for inductive loads. This is very unsatisfactory. Almost every load that an alternator has to carry is to a certain extent inductive, *e.g.*, arc lamps, transformers on light loads, rectifiers, induction motors and synchronous motors unless the excitation is carefully adjusted. And as the regulation of an ordinary alternator on $P\,F = .95$ is about twice as bad as on $P\,F = 1$, it is obvious that a fairer guarantee would be to give regulation on inductive loads. Practically the only exception to this is the case of an alternator for use exclusively for running synchronous converters. And even with a compound-wound synchronous converter and an inductive line, the power-factor is usually low and the current lagging for low loads, and if the rotaries have to be started up from the a.c. side, a generator with poor regulation on low power-factors is very noticeable and may give trouble.

It is extremely difficult to measure the regulation for $P\,F = 1$ on any machine with good regulation, while on a large machine it is practically impossible. The result only comes in as the difference between two large quantities, and there are so many disturbing features that the result when obtained is not worth much. On the other hand, it is quite easy to measure the regulation on a very low power-factor by taking a second machine and running it as a synchronous motor, the first one running as a generator; And then varying the excitation of the motor and generator till we get full-load current flowing at full-load voltage; the power-factor in the test will be very low and can with sufficient accuracy to be taken as being zero.

Alternators can be designed so as to satisfy a pretty good regulation specification for non-inductive loads and yet be almost worthless for carrying loads of low power-factor. And as such machines can be made cheaper than if they had to give a reasonable regulation on inductive loads, there is a temptation for manufacturers to take advantage of the fact that the regulation is only guaranteed on $P F = 1$, and to put in one of these cheaper machines. It is probably this fact that is responsible for the number of alternators having poor regulation on low power-factors, that have been installed in this country. It would certainly be an advantage from the customer's point of view and probably in the end from the manufacturer's point of view also, if the regulation were guaranteed for a load of low power-factor. This would make it necessary from the commercial point of view to alter somewhat the lines on which modern alternators are designed, but the cost of the machines would not necessarily be much increased. A modern alternator gives, say, 7 percent regulation on $P F = 1$, and 22 percent on $P F = .8$. When running with a normal power-factor of about .85, and a regulation of about 17 percent, it does not do the station engineer much good to know that if he had a non-inductive load he would have good regulation. Such a machine could be re-designed on somewhat different lines, so as to have 6 percent regulation on $P F = 1$, and 12 percent on $P F = .8$, and about ¾ percent lower efficiency without increasing the cost more than 10 percent. Such a machine would be much more satisfactory for general work and could probably be sold for considerably more than the machine designed only for work on non-inductive loads.

Other things being equal, the regulation of an alternator is better the more saturated the magnet circuit; this applies to low power-factor loads as well as to high. This can be considered simply as an experimental fact, or the explanation can be accepted that the voltage drop in an alternator is partly due to the reaction of the armature ampere-turns, and that the effect of a definite percentage change in the ampere-turns is less when the magnets are saturated than when they are not.

Obviously the part of the magnetic circuit to saturate is the magnet core, as the less its cross-section the less its perimeter and the less the weight of the magnet copper. In the type of magnet, shown in Fig. 7 it is impossible to saturate the pole core, and the large amount of iron and copper necessary always makes this design needlessly extravagant. It, however, possesses the advantage that the voltage can be raised 25 or 30 percent, if desired, to compensate for an extraordinary line-drop. Usually, however, it is sufficient if an alternator is capable of having its voltage raised 15 percent when carrying full load.

When designing an alternator for a given output we can take either a strong armature and a weak field, or a weak armature and a strong field. And generally speaking, the stronger the armature we work with, the cheaper the machine but the worse the regulation. So to design cheap machines with good regulation, we have to take advantage of everything that will better our regulation, *i.e.*, we must work with a long air-gap and we must saturate our poles. But a long air-gap means large leakage, and as I pointed out before, a machine with large leakage and saturated poles is the most difficult machine of all to design. And to make a uniform success of these machines, the designer must have had considerable experience with the type of machine in question, and must be a very careful worker. In fact, when I first started designing alternators I was told to put plenty of iron and plenty of copper into the magnets and then I would be safe. I followed this advice and was always safe with my machines. I think for a beginner the advice is very good and that he could not do better than to start in with a conservative and simple design like that shown in Fig. 7. But for a designer who has had considerable experience, it is worth while to attempt cutting things fine, because there is quite 20 percent in the cost to be saved by doing so.

We are working with a large air-gap and yet wish to keep down the leakage. There are several things which will help us in this, but making the pole pitch large and decreasing the length of the magnet pole are the most important.

Making the pole pitch large means making the machine larger in diameter, and shorter. Beyond certain limits this increases the cost of the machine, and it is a question to be decided by the designer as to when the advantages obtained from the larger pole pitch are offset by the increased diameter and weight of the castings.

Decreasing the length of the magnet pole core decreases the leakage. Decreasing this length means decreasing the radiating surface, increasing the depth of the magnet winding and hence increasing the length of mean turn of the magnet coil a little at the same time, and slightly decreasing the ampere-turns for the magnetic circuit. If we use large pole pitches, giving plenty of space between the poles and short armatures and high peripheral speeds, we can easily take care of the increased temperature due to decreased radiating surface. So that the limiting factor in decreasing the length of the pole core becomes the increase weight of copper due to the increased length of the mean turn of the magnet winding, caused by the extra depth of the winding. With good design we can usually cut down the length of pole core to about 1 inch for every 1500 ampere-turns required on full load. So that our leakage-coefficient will generally not exceed 1.25, which is not excessive.

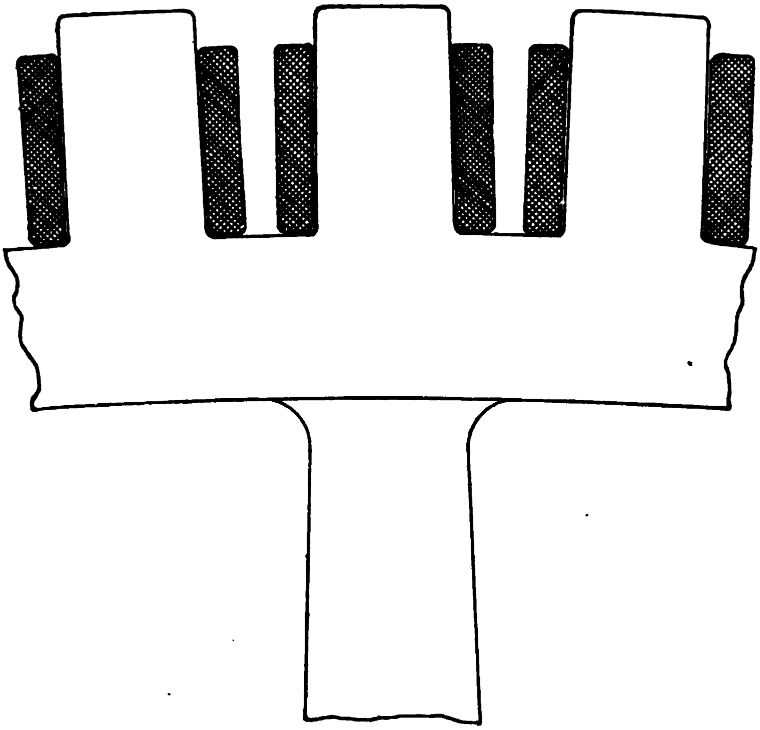


FIG. 7.

To show the effect of these various points on the design of a machine let us take a definite example.

Output 750 kw. 60 cycles, 100 r.p.m., 72 pole, 2200 volt. Specification to be:

Efficiency at full load 95 %
Regulation 7% for $PF = 1$
" 16% for $PF = .8$
" 25% $PF = 0$

Temperature rise on full load $PF = 1$, Armature 30°C., Magnets, 20° C. (To take care of the increased excitation on loads of low power-factor.)

A is a machine which has a pole pitch and diameter large enough to use round poles, and has saturated pole cores. It has a strong armature and strong magnets.

B has a smaller pole pitch, and is a longer machine and has unsaturated fields. It has a fairly weak armature and field, and the magnet winding is crowded.

	A.	B.	C.
Internal diameter of armature	207"	161"	207"
Length of armature core	6¼"	13½"	6¼"
Pole pitch	9"	7"	9"
Air-gap	5/16"	¼"	5/16"
Peripheral speed	5400	4200	5400 r.p.m.
Slots per pole	6	6	6
Turns per coil	5	3	4
Magnet core section	round	rectangular	round
Induction in magnet core	110000	95000	110000
Regulation $PF = 1$	7%	6.8%	5.6%
$PF = .8$	15.5%	16%	10%
$PF = 0$	24%	25%	16%
Losses magnet I^2R.	12500	8500	17000 watts
Armature I^2R.	10700	7250	12000 "
Iron-loss	15200	24000	19300 "
Efficiency	95.1%	95.0%	94.0%
Temperature rise of armature	22°C	30°C	26°C
" magnets	15°C	16°C	26°C
Weight magnet copper	1800	3800	2300 lbs.
" " poles	1420	4500	1780 "
" " wheel	14000	15000	16000 "
" armature copper	1425	1200	810 "
" " laminations	5500	7500	6600 "
" " frame	22000	18000	22000 "
Cost of above material	$1,645	$2,150	$1,710

So on the principal items that enter into the cost of material, the saving is about 25 percent Probably the saving of the cost of the complete machine would be about 20 or 25 percent. The designs of these two machines are a little exaggerated but they show very well the saving in cost that can be made.

C is the same machine as A but designed with a weaker armature, so as to have better regulation especially on low power-factors, at the expense of a lower efficiency. The cost is about the same.

The chief points for a cheap design are strong, saturated magnets, a reasonably large pole pitch, and as large an air-gap as can be run without excessive leakage. In machines of small output with a large number of poles, it is impossible to get a really cheap design. The diameter is decided by the number of poles and it is no use making the machine less than 5 or 6 inches long, so the cost does not come down very much with the output. Generally speaking, if the ouptut of the machine is less than 10 kw per pole, the design is unnecessarily expensive, while machines in which the length of the armature is about equal to the pole pitch usually come out the best. It is for this reason that 60-cycle alternators for small outputs and 120 or 133-cycle alternators of all outputs are usually made belt-driven. The saving in cost by this means is often 50 percent. In continental Europe where 50 cycles is the usual practice, belt-driven alternators have never met with much favor. The universal custom is to direct-connect the alternator to a low-speed engine. The result of this has been that the fly-wheel type of alternator has practically become standard; the poles of the alternator are simply bolted to the rim of the fly-wheel. This type allows considerable saving in cost in small 50 or 60-cycle machines and possesses so many other advantages that it is being gradually introduced into this country.

Alternators for direct connection to steam turbines have lately come into prominence. The chief consideration in these machines is, of course, the high speed at which they run.

In order to keep down the length of the machines, they have to be made with the diameter as large as possible, so that the peripheral speeds run from 12000 to 15000 feet per minute. The tensile stress in the steel is not so bad, the chief difficulties lie in getting the mechanical strains on the insulation of the rotor to be taken in such a way that the insulation is not damaged, and in getting the rotor properly balanced and to run without making excessive noise.

The electrical design is much the same as that of belt-driven machines, except that the speed being so high the efficiency is very good, so that the densities in the armature can be considerably higher. The pole pitch and the ampere-turns on the armature being large, the magnets are of necessity very strong and the air-gap large, and it is as much the magnetic leakage as the difficulty of getting sufficient cross-section in the magnet iron to carry the flux, that decides the output of the machine. In these machines just as well as in low-speed machines, strong magnets and high density in the magnets give cheap machines. But good mechanical design will have far more effect on the cost than would be the case in a low-speed machine.

When starting to work out a machine, an experienced designer can guess pretty exactly the best diameter on which to build it. And he knows from experience approximately the number of ampere-turns he can take per inch periphery on the armature for a machine of a given pole pitch and type. This gives him at once the number of turns on his armature and the ampere-turns on the magnets. He then completes this first rough design, and working out its performance curves he can usually see very quickly in what way to improve it so as to obtain the best design possible under the circumstances.

FIG. 8.

The speed and frequency are the chief factors in deciding the design of a machine, but the voltage, the condition of operation, the equipment of the factory in which it is to be built, the facilities for obtaining castings and for shipping the completed machine—all are points which affect the design and have to be considered by the practical designer, since the prime object in a commercial design is rather to make profits for the manufacturing company than to produce the most perfect machine. The points that have to be taken into consideration are so numerous and varied that it is impossible to give general rules for practical design. All that can be done is to give general directions and after that it is a question of ability and experience till the engineer can produce the best results.

Neglecting for a moment the designs of Mr. C. E. L. Brown, the greatest change in the design of alternators in the last ten years is the improved ventilation and the increased magnet strength. In 1893 we were working with air-gap densities of 25000 to 30000 and magnets giving 3500 to 4000 ampere-turns per pole on full load, while to-day we have air-gap densities of 60,000 to 70,000 and magnets giving anything up to 20,000 ampere-turns per pole on full load for ordinary belt-driven or engine-type machines, and up to double this on steam-turbine-driven machines. The change has been made so gradually that it has hardly been noticed, but the effect can be seen if I give the dimensions on two machines designed and tested, one in 1894 and the other in 1903. Both the designs are typical of the condition of the alternator design at those dates.

	1894 Machine.	1903 Machine.
Output	50 kw Single-Ph.	275 kw 3-Phase.
Speed	600 r.p.m.	600 r.p.m.
Cycles	60	60
Type of magnets	Lauffen Type.	Standard Rev. Field Type.
Internal diameter armature	37″	38″
Length of armature laminations	10½″	10″
Armature ampere-turns	1380	1050
Ampere-turns on magnets	4700	7500
Efficiency	90%	94%
Regulation $PF = 1$	11%	5.5%
“ $PF = .8$	Would not give volts	14%
Temperature rise of armature	31°C	23°C
Total weight of copper	730 lbs.	680 lbs.
Total weight of machine	7400 lbs.	11000 lbs.
Total cost of material (2-bearing machine)	$455	$490

The output has come up about four times and we have a much better machine as regards performance, and the cost is about the same. The older machine having such a low output needs a lot of unnecessary material, simply to reduce the losses and to give a reasonable efficiency. While in the large machine we can afford a far higher loss without spoiling our efficiency, so that the weight of material is really not so much more and the better mechanical design has made the cost of material in the two machines about the same. Speaking generally, the whole result has been accomplished by using stronger magnets and higher densities throughout.

Alternating current design has rather stagnated of late on account of the limited competition, and most of the recent developments have come from the other side of the water. But I think there is enough in this paper to show that from the point of view of dollars and cents, it certainly pays to spend time and ability pretty lavishly in designing alternators.

DISCUSSION.

MR. WATERS:—I think this is a suitable opportunity to emphasize the advisability, from a commercial point of view, of guaranteeing alternator regulation for power-factor = 0 rather than for power-factor = 1. It is true that the INSTITUTE Committee on Standardization has formulated a rule for calculating the regulation on non-inductive loads from a short-circuit test, but I think there is a general concensus of opinion among alternating current designers that the rule is very unsatisfactory, and that for certain classes of alternators it gives results which are absurd. And I suggest that it would be a good deal more to the point if the Committee would recommend that the regulation be guaranteed for power-factor = 0, as this gives the behavior of the alternator under the worst possible condition, and in addition a direct test can be made to determine whether or not the alternator fills its guarantee, instead of relying on a calculation based on arbitrary assumption, the accuracy of which there is nobody to vouch for in cases of dispute.

MR. DAVID B. RUSHMORE:—The generator is one of the important elements of a transmission system. The regulation of the system is largely dependent on that of the generator.

There are certain peculiarities of high-voltage power transmission which differentiate, to some extent, the requirements which a generator must fulfil from those in other kinds of work. The voltage of the line, and sometimes of the generator, is high. The long lines offer a great many opportunities for trouble, so that grounds and short-circuits are of frequent occurrence, and the number of severe strains on the apparatus is large. Some systems have a considerable proportion of the output utilized by induction and synchronous motors in large units, which, when used for mine hoists, or in case the latter are started by being thrown on the line, make the problem of satisfactory lighting one requiring care. Lightning troubles are more frequent as the length of line is increased and storms are of greater violence in mountainous countries.

Δ OR Y CONNECTIONS.

The question as to which type of connection is better is important. The reasons which apply for and against each type of connection for transformers apply with equal force to the generator. One point of especial interest is the effect of a Δ connection in a system having a pronounced third or ninth harmonic. Capacity in the system tends to amplify, in the current curve, any harmonics which may exist in the original emf wave. Now in a generator armature, or transformers having a Δ connection, the third harmonic instead of having a phase difference of 120° in the different legs is directly in phase as shown in Fig. 1, and tends to send a circulating current around the delta. In one experimental alternator the current in the delta was full-load value. As this current is limited by the resistance and inductance of the generator and not by the " synchronous impedance " it is less in machines of high inductance. Modern generators are built with wave forms which follow so closely the sine law that this fact is of perhaps more theoretical than practical interest and yet should be borne in mind as a possible explanation of phenomena occasionally found in practice. A small amount of static capacity is desirable in a generator and it should be less with a Y than with a Δ armature connection owing to the fewer turns on the armature. A bad short-circuit may burn out two-thirds of a Y-connected armature and but one-third of a Δ.

It is especially with regard to regulation that generators should be suited to the line and conditions of service.

Good regulation is desirable for the following reasons:

The voltage will not rise to so great a value on sudden opening of receiver circuit;

Less careful attendance is necessary as the change in exciting power for variation in load and power-factor is less;

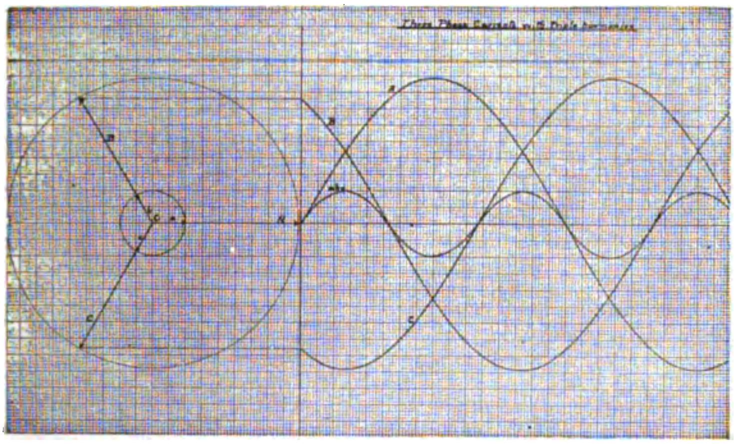


Fig. 1.

Induction and synchronous motors may be thrown on line with less disturbance.

Fair regulation gives the following characteristics:

Disastrous results from short-circuits are prevented;

Generators have stronger synchronizing power and make better synchronous motors;

The charging current raises the voltage at the generator terminals;

The short-circuit current is less and the operation of automatic devices for opening the circuit may be easier;

Better efficiency and a less expensive machine may be had than when the regulation is better;

More even division of load with less cross-current and better parallel operation;

The operation of lightning arresters will be more satisfactory.

Bad regulation produces:

Abnormal variation in excitation and bad regulation of system.

Excessive rise of voltage due to charging current:

Ability to run machine on short-circuit momentarily without injury;

Disastrous effects from sudden inductive loads.

Occasion is here taken to call attention to a point in theory in which an error may have been made by some writers. It has been considered by many that when the iron is saturated, in either the armature teeth or the pole corners, that the cross or distorting ampere-turns weaken the field by being unable to increase the flux as much in the strengthened pole corner as it is decreased in the weakened pole corner. So far as is known to the author, every writer, with the exception of Mr. C. C. Hawkins, has adopted this view, and a number of theories and diagrams for predetermining alternator regulation have been based upon it.

No experimental proof has been shown to uphold it, but, on the contrary, much that exists points the other way. Brush-lead in a continuous current dynamo and power-factor in an alternator, are in very close correspondence. In tests which have been made on field exploration of continuous current generators and speed tests on separately excited motors, both with local saturation and the brushes at the neutral, the evidence, while not conclusive, points to the fact that the field is not weakened by armature reaction under that condition. In an alternator, with current in phase with the no-load e.m.f., which could be obtained with a leading terminal current, the drop in the armature should be due only to true armature self induction and resistance, except for minor causes, as variation in power-factor of field. That is; with non-inductive load, in armature of an alternator and with brushes at neutral in continuous current generator, the cross field formed by the distorting ampere turns of the armature represents pure armature self induction and is not interlinked with the exciting turns. The number of magnetic lines added on one side of the pole must exactly equal those subtracted on the other, owing to the different densities, in both air and iron, the magnetomotive forces, and not the fluxes, are unequal on the two sides.

The wave-form of the generator should be a sine wave and the amplitude of any harmonic should not exceed from 3 to 5 per cent of the fundamental. The various pieces of apparatus through which the energy passes and the capacity of the line, transformers and armature, will all tend to cause distortion.

RALPH D. MERSHON:—I have not seen this paper before, but there are few things mentioned in it which have struck me and with which I cannot quite agree. One is the temperature rise on full load. I do not see any use in a temperature rise as low as

30°C. I do not think any of us will get anything from the electric companies that we do not pay for, and I think we will pay for a 30° rise all right. If not when the company first starts in business, we will later. A rise of 40° or 45° is certainly safe with modern insulation. I think the practice of the European engineers has a good deal to commend it. They ask for a machine that will rise 40° under full load, and that is what they mean. They pay for a machine that rises 40°, and do not pay for anything more.

There is a statement made here in regard to the regulation. The author says, " In Europe practically every alternator sold has to run motors so that the regulation either for power-factor .8 or for power-factor 0 has to be guaranteed." Judging from some generators I have seen lately it must in some cases be guaranteed pretty high. I saw not long ago some European alternators of from 1200 to 2000 h.p. capacity. They were some of the most beautiful machines mechanically I have ever seen, but electrically I thought them bad. When I say " bad," I mean from the standpoint of our ideas as regards regulation. Those machines must have had a very poor regulation on any power-factor less than unity, and I do not believe we could have gotten any satisfaction from them in our plants with a power-factor of .8; certainly not with the attention that is ordinarily given here to the operation of machines. There was another evidence, in most of the European plants I saw, that the regulation could not have been very good. It was the switching arrangements. In many cases there were no switches intended to break the load in case anything happened and in no case did I see a switch which could have handled a short-circuit if the generator had had stiff regulation. In most cases on asking what was done when a short circuit occurred, I was told that they shut down either all of the plant or that portion of it which happened to be feeding the line on which the short-circuit occurred.

HARRIS J. RYAN:—I want to say just a word in behalf of the Committee on Standardization. At the outstart of the present year the Committee appointed one of its members, a well-known consulting engineer, to take up with the electrical engineering profession in this country the regulation of alternators, with a view to making a new formulation of the wording and specification of procedure in Section 71, I think it is, of the Standardization Code, or report, as it is variously called; and that member of the Committee in taking up this work—and he did a great deal of work in this respect—found that as yet, at least at this immediate time, the concensus of opinion of the profession was such as not to be prepared to accept any one wording that could be formulated to suggest to the INSTITUTE to be substituted for the present wording. The matter is well in hand and at a comparatively early date we hope to be able to report a suggestion for a satisfactory wording of that section.

Mr. Waters:—There are one or two points in Mr. Rushmore's remarks which I do not quite agree with. Mr. Rushmore calls attention to the fact that in designing alternators for running on long transmission lines, we have to allow for the numerous short-circuits which take place, thereby, I suppose, intimating that an alternator with good regulation was hardly satisfactory for this work. I think that this is altogether wrong. When you have a short-circuit on the system, the general practice is either to burn it out or else have the circuit-breakers cut it out. If you have an alternator with bad regulation and leave it on the line, it merely means that the pressure decreases, so that the motors fall out of step and the plant shuts itself down, the voltage not being sufficient to burn out the short-circuit.

In connection with inductor alternators, I did not mean to suggest that an inductor alternator cannot be made with good regulation. They certainly can. If you take a 200 k.w. alternator and rate it down to 100 k.w., you will probably get a machine with very good regulation, but it will not be a commercial machine. My paper was dealing with the question of dollars and cents in connection with alternator design, and I say that a revolving-field alternator designed as I have suggested is simply above comparison with an inductor alternator on a question of cost, the difference being a matter of perhaps thirty per cent.

[Communicated After Adjournment by Mr. W. L. Waters.]

Referring to Mr. Mershon's remark that he did not know that the temperature rise of a machine was determined by the mechanical design. I would point out that the temperature rise depends on two things: The watts to be dissipated in the machine and the rate at which they are radiated. The watts to be dissipated depend on the output of the machine and on the efficiency; and the efficiency is decided by the market standard, being a commercial rather than an engineering question. So we can say that the watts lost in a machine are independent of the design, and hence that the temperature rise depends only on the facilities for radiating a given number of watts, that is on the ventilation or mechanical design.

President Scott:—The paper on Institute Branch Meetings, prepared by Mr. Calvin W. Rice, the chairman of the Committee on Local Organizations, will be read by Professor W. E. Goldsborough who is also a member of that committee.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, June 29, 1903.

INSTITUTE BRANCH MEETINGS. THEIR ORGANIZATION, DEVELOPMENT AND INFLUENCE.

BY CALVIN W. RICE.

To any one looking over the work of the INSTITUTE of this year and comparing it with that of previous years, there will immediately appear an increased scope of usefulness of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. The situation is seen at a glance by looking at the last pages of your program for this meeting, showing the magnificent array of local branches installed and regularly conducting meetings. The credit for the activity is very much due to your President, Mr. Scott. It has been one of the features of his year's work, the broadening of the influence of the INSTITUTE, and on a very high plane.

The idea of branch organizations was given a number of years ago, and the Secretary, Mr. Pope, made a report on it. However, the President at that time did not favor the movement as he was fearful that it would weaken rather than strengthen the INSTITUTE. Some thought has been given to this contingency, yet at no time has the Committee considered it serious. We have gone ahead on the principle that the work is right. that it is for the benefit of the INSTITUTE and of Engineering and that if we properly conduct our meetings there will be strength in them; and one need not fear that the movement will promote separate engineering societies in the different cities which will divorce themselves from the central organization.

The oldest local branch is the one in Chicago. This was established in 1893. and has been regularly maintained. An average of 7 meetings has been held each year with an average attendance this last year of 70. The next one to be established was at Minneapolis, April, 1902. The larger number, however, were established in the fall of last year, and the spring of this year. The largest number of meetings held was at the University of Wisconsin where during the last year 30 meetings have been held.

It was thought at the beginning of the year that the organization of local branches should be in accord with a definite prearranged plan and it was proposed to map out a specific plan to be adopted by each branch. On account of pressure of business, the Committee on Local Organization was unable to go into all the details of organization, and it has since proved that perhaps this was an advantage, rather than a detriment. Greater spontaneity has thereby been secured and a variety of successful methods have been developed, adapted to various conditions.

I wish that time permitted the reading of all of the reports which have been received from the several branches. These have been prepared with care, sometimes the entire Executive Committee met together to formulate the report and recommendations, and the INSTITUTE owes its thanks to them for all the work they have done

Some of the principal features that one notes in reading the reports and in our general observation of the progress of the year, is that, whereas meetings in New York may be technical or special, meetings in Local Branches must be general. In all the reports, one finds that to maintain interest, there must be more than one set of people on whom we may draw for our audience. Quite a number advocate, very properly, joint meetings with other engineers. Some others are positive that in their locality our meetings should be conducted independently of other societies, but this opinion is in the minority.

A very interesting feature of the work has been the large attendance of non-members of the INSTITUTE at the meetings. Outsiders are attracted to the meetings. Ten or a dozen members may manage a meeting of a hundred. This illustrates the power we have within us if actuated by the right principles and on the right plane.

It is generally suggested, as mentioned above, that all engineers, regardless of their affiliations, should be invited to our meetings. It may be that we do not care to join in their meetings, but we should invariably invite all engineers to and make them welcome in our meetings.

It has been almost universally reported that the papers of the last year have been so diversified and of such an interesting character that in but one or two cases has there been any necessity for papers to be prepared on local subjects in order to maintain interest. I think this is speaking a great deal for the variety of subjects and general usefulness of the papers presented during the last year. Special thanks also are here given, and we trust the word will be passed along to the speakers themselves, to those authors who have not only inconvenienced themselves to write papers, but to come to New York to read them, and have again read them at some of our branches, all of which has tended to promote the very best interest in the INSTITUTE work.

A very good suggestion is that in the branch meetings the New York papers be read by abstract only, and that well-informed men be called upon to give the abstract of the paper and of the original discussion. It is quite uniformly agreed that the discussion, when the same as that in New York, need not be printed, but it is recommended that the Editing Committee give credit to each speaker who gave opinions along the same lines. One good suggestion is that the editing of each Local Branch be done the next day after the meeting by the Committee in charge of that branch. Another suggestion is that all papers should be sent to the local branches with the abstract prepared. These abstracts and the papers themselves to be sent out earlier, and still greater efforts should be made on the part of the Committee on Papers the coming year to try to get the papers sent well in advance of the meeting.

One of the evidences of the substantial work done is the request even now for next year's program and also in the suggestion that in Universities the members of the junior class be put on the committee to take part, so that next year a working committee will already have had some experience.

One special point made in the suggestions received is that definite responsibility for the success of the meetings should be placed upon some one individual. He may have a Committee to assist, but some one person should feel that the success of the meeting is dependent on him.

An indication of the work of the year has been the increase in membership, the work of these branches being carried on hand in hand with the Membership Committee and the other influences of the INSTITUTE. In the May announcement, you will find the increase in membership in half a dozen cities alone, where we have local branches, has been about 350. The total increase for the year up to May 1st has been stated in the April announcement in the neighborhood of 850. Whereas it would not be fair to assume that the whole credit should be given to any one feature of the INSTITUTE, still, it is hoped that the INSTITUTE will give due credit to the hard work of the various local executive committees and secretaries who have kept up the interest throughout the year in the meetings at various branch centers and thus made the INSTITUTE felt as it never before has been.

At the beginning of the year an appropriation of $1,000 was asked to carry on the work of the season. The expenses of the year, as reported in the Secretary's statement of June 19th, have been $849.64. It has been the uniform practice to offer to meet the reasonable and necessary expenses of Local Branches, it being considered that we should do this, for the reason that the members that have subscribed their yearly dues should not be further called upon to contribute. At one point, the local membership have been assessed one dollar by their own committee; such contributions should be voluntary rather than obligatory.

From a financial point of view, therefore, upwards of 300 members have been either influenced or encouraged to join the INSTITUTE, due to the activity of the Local Organizations, bringing into the INSTITUTE immediately $1,500 and a probable permanent annual income of $3,000, and at an outlay of less than $1.000; this without reference to the Student enrolment. This statement is simply to show that the movement has been self-supporting, to say nothing of the remarkable increase of influence and power of the INSTITUTE.

I cannot do better in closing this report than to quote the remarks of the secretary, Mr. Philander Betts, of the Washington Branch: " We are unanimous in our desire to have our meetings so conducted that they will become a common meeting ground for all engineers."

DISCUSSION.

PRESIDENT SCOTT:—At the beginning of the year when it occurred to me that the Institute might work in a field in which it could come in contact with the college student, carrying to the students something of the spirit of actual engineering work, I wrote several letters. On the whole, the best answer that I received was from a gentleman who is here to-day, who took up the idea with a good deal of interest and vigor. During the year he has fostered the Institute branch meetings in the institution with which he is connected as head of its electrical engineering department. I am interested to know what he thinks of it at the other end of the year. I am going to call on Professor Ryan of Cornell University to open the discussion.

PROFESSOR HARRIS J. RYAN:—I am more enthusiastic over the scheme that we have just heard of in the paper written by Mr. Rice than I was in the beginning, and in connection with my letter in which I expressed my enthusiasm to your President; I want, in speaking in behalf of the branch at Ithaca, those in charge of the work and our young men who are members of it, to express to the Institute our heartiest thanks for the kind courtesy shown in inaugurating this scheme and for what you have done for us. There we have, practically, the work of the local branch as a part of the regular work in electrical engineering instruction. It is not exactly required, because we felt that in inaugurating the work there it was important that the work on the part of the individual student should remain his own choice as much as possible. However, attendance at the meetings and taking part in the work secure credit in lieu of required work in the regular course of electrical engineering instruction. Our plan is to abstract the papers, to present them before members of the senior class and certain members of the junior class that are well on with their work, together with all local members of the Institute resident at Ithaca; to abstract these papers and then interpret them to the students, using for this purpose the more able members of the senior class and graduate class assisted by the officers of instruction, and likewise with the assistance of the local resident members of the Institute. We supplement the work with biographical accounts, brief sketches, of the careers of the men who are the authors of the papers, so that the young men go forth with a little knowledge, at least, of the men who in electrical engineering matters are a power in our nation. When the reports of the discussions come, those are gone over, sometimes abstracted and in abstract form presented to the students, and sometimes *in toto*. The young men take great interest in the discussions, as well as in the papers; for the reason that the off-hand subject matter they can comprehend at once right then and there; and in this manner the effect and the results of this movement on the part of the

Institute, with us, have fully met the expectations of your president and the gentlemen who have inaugurated the scheme.

PRESIDENT SCOTT:—In connection with the local movement there is one gentleman who has a unique prominence, being at the head of two of the local organizations, one in a university (Purdue), the other in a city (St. Louis)—Professor Goldsborough.

PROFESSOR W. E. GOLDSBOROUGH:—As regards the local branch movements at Purdue and in St. Louis, I think they have both been quite successful during the past year.

When the year opened we had at Purdue an electrical society which had been in existence four or five years; we now no longer have a Purdue Electrical Society, but the Purdue Branch of the American Institute of Electrical Engineers, and this is the only electrical engineering organization at the university.

The meetings stimulate our young men, and bring them into touch with matters outside of the university in a way that is distinctly good. We have not given the boys any official credit at Purdue for the work which they have done in connection with the Institute meetings. That is, we do not recognize this activity as being a university exercise. It has been, with us, a means of stimulating the young men to make their own success of the meetings; and the members of the faculty take just as little part in the meetings as possible. We want to have the boys learn to do these things for themselves.

At St. Louis we have held meetings regularly every month, and to our secretary, Mr. Swope, I think the success of our work is due. If we can have a man devoting as much time and energy to the Institute meetings in each city as Mr. Swope does in St. Louis—and I doubt not other secretaries are quite as energetic—it will mean that in the course of a few years we will be having "New York meetings" everywhere, and it will be quite as much a treat for the New York members to have our discussions as for us to have the New York discussions.

PRESIDENT SCOTT:—I wish we had time to read the letters that Mr. Rice spoke of. There are quite a number of them, but it is hardly practicable to read them here. One of the good letters was from Mr. Junkersfeld, secretary of the Chicago organization.

PETER JUNKERSFELD:—As for our work in Chicago, as stated in the report, it is one of the oldest, if not the oldest, branch of the Institute. For several years the meetings, while they were held at fairly regular intervals, could not bring out a very large attendance, one reason being perhaps that there are two other engineering societies in Chicago.

One of the points that I think deserves perhaps a little more mention is the fact that an effort should be made to hold our meetings before the discussion is printed in the various electrical papers. We found in Chicago, where the meetings were usually held ten days after the New York meetings, that the matter was just a little stale. The members had read all the New York discussion, and they felt that everything possible had been said; and I think if the papers were sent out promptly and meetings held before the discussion is published, the whole matter would be fresher and we would really get more local discussion and more local interest. That is a point that we feel in Chicago particularly.

Then there is a serious question, too, as to the influence of the other societies. The work has been going on harmoniously and all of them have very good meetings, but if we could combine our efforts, which we may be able to do at some time in the future, we think it would be very beneficial to the Institute.

PROFESSOR RYAN:—Speaking in behalf of the Ithaca branch, I would like very much to say that they would be heartily pleased to contribute to the expense of the maintenance of that branch. It certainly must cost quite a little to furnish us the large number of reprints of the papers as the Institute has during the past year. A large proportion of the class in the outset said that they would be perfectly willing to pay the regular price of the transactions in order to get those papers. Naturally, the matter was not taken up further when the papers came along without price.

PRESIDENT SCOTT:—I would like to ask Professor Ryan how the new student privileges meet the demands of these universities.

PROFESSOR RYAN:—I think that 60 to 75 per cent. have not tried it yet, it was too late in the year. It probably will entirely meet the demand. That is my impression.

SECRETARY POPE:—I see that the branches call, as members have called and meetings have called, ever since I have been Secretary, for the earlier publications of the papers. With competent assistance at headquarters, and the use of the typesetting machine, and rapid processes of engraving, we practically rival the evening newspapers in getting out our edition of advance papers—when we get the copy. We have gone so far as to rewrite papers, but we have not yet originated them. When the actual authorship of papers is delegated to the Secretary's office perhaps we will be able to get them out a little earlier.

So far as the Secretary's office is concerned with branch meetings I feel that we have not really done justice to the work. We have a great many other things to attend to, and they all come along in a bunch, and it has grown on me during the last year that this was work for some one man to do, who was interested in it, and familiar with the requirements, and perhaps one of these local secretaries mentioned will develop some day into a general local secretary to take care of the branch business. Really, it has become sufficiently important, as we may see from the experience of the last year. Before they were fairly started, we began to see the end of the season, but we are now in better shape, so that we can make an earlier and a better start next year; and if the interest keeps up, as there is every reason to believe it will, the branch movement will be a very important part of the work of the Institute, and you can see from what these gentlemen have said to-day that it is of importance to the future of the Institute. These young men coming up learn not only of the work of the members, but of the personality of the members themselves—their biographies, who they are. They come to our meetings, and they meet the older members face to face, and when they go out into the engineering world one of the first things they will find they require to qualify them is to become members of the Institute and coöperate with others in the general progress. Now, this is the work not only of the branches, but also of the student enrolment which has been inaugurated, and which, as you are probably aware, is limited to three years. No one can be enrolled as a Student for more than three years, after which time it is supposed he will become eligible and will become an Associate; and in the discussion, and in the formation of that enrolment, as we call it, of students, the whole object of that work is the future of the Institute. We have undertaken the work at a loss. It doesn't pay the expense of carrying it on; but what we look for is the future development that will come from the enrolment of these students and the training them up in the way that they should go.

MONDAY.—EVENING SESSION.

President Scott:—In the American Institute of Electrical Engineers a large part of our work is the recording of what has been done, the getting together of data, the description of electrical work that has been accomplished, in order that we may know what has been done, and how new work should be done, as a basis for the future. We also extend out from the present and from what has been accomplished, to that which is to be accomplished along the same lines. For example, we have the electric railway accomplishing certain things now, but advancing on to new lines of activity, to higher speeds and heavier work.

Another department of work in which it is from time to time the privilege of the Institute to take part, is that in which we branch out into the new things, where scientific discovery of a new order in its application to useful ends brings to us a new kind of phenomena, a new kind of application, and it is to work in this field that we are to be treated with a presentation to-night. The carrying of electricity through gases and the illumination of gases, which a few years ago was simply a scientific experiment, is now brought into practical use through the experimenter and the engineer. It is our privilege this evening to have explained and demonstrated to us some of the latest developments in this line, which are giving great promise for the future, as they deal with certain operations of lighting and current transformation which are of the greatest practical and commercial value.

The main presentation will be made by Dr. von Recklinghausen who will be followed by Mr. P H. Thomas, who will describe the apparatus. I have pleasure in introducing Dr. von Recklinghausen.

DR. MAX VON RECKLINGHAUSEN:—Since the Hewitt lamp was first shown, at the Conversazione of the American Institute, two years ago, this type of lamp has aroused the greatest interest throughout the world. A steadily increasing number of electricians and physicists have stepped into this so intensely fascinating, newly opened, or, to be more exact, re-opened field of research. We may therefore expect a speedy development of the mercury lamp and its many-sided applications.

I thought it would be appropriate at this stage of the art to look back on the earlier work in this direction, particularly since the principle underlying the Hewitt lamp; that is, the passing of current through mercury vapor, is one of the very oldest ever applied for the generation of electric light—older, really, than our whole electrical industry.

As early as 1860 Professor Way of England demonstrated the enormous candle powers obtainable by using mercury vapor as a conductor of the electric current. He used for his lamp an apparatus having two reservoirs, both of them filled with mercury. Each reservoir was connected with one pole of the line. A little cock was opened on the upper reservoir, and mercury was allowed to flow through to the lower reservoir The current going through that fine stream of mercury heated the stream and brought it to evaporation. The current formed, then, an arc between the nozzle of the upper reservoir and the surface of the lower reservoir. He seems to have tried this not only under atmospheric pressure but also in a vaccum. Way examined in detail the color of the mercury light obtained in this manner, and he remarked on the strange look of things and faces in the light. We have some extremely enthusiastic reports from that time in the newspapers as well as in the reports of Trinity House, the English Lighthouse Commission, on the enormous far-carrying candle power of the mercury vapor light obtained by this means. Had the current sources at that time been more commercial—they being primary batteries, of course—who knows whether the green-blue of the mercury lamp would not by this time have become indispensable to us? Whether we should not have become so used to this color of light as to call the color of faces exposed to it beautiful? After all, beauty is only a matter of custom.

Other problems, more important, came up in the electrical field, and the mercury lamp was entirely forgotten for a good many years. The first we hear about it is in a patent granted to

Rapieff in 1879. Rapieff used an inverted glass U, the two columns of which were filled with mercury. It was constructed about like this, (indicating)—the U was tilted over so as to allow the two mercury columns to connect; then the U was tilted up again, and after the metallic connection was broken, current went through the gas above the columns. In his patent he does not speak very fully of what the gas must be. He mentions mercury vapor. He says one can also apply a vacuum.

A patent by Rizet, of March 20, 1880, described a very similar U-shaped lamp. Rizet proposed early to alter the green-blue color of the mercury vapor by having certain gases filling the space between the mercury electrodes. Amongst others, he proposes nitrogen, which gives a reddish discharge.

In 1887 Langhans obtained a patent for a U-lamp practically the same as the one that Rapieff first made. How far those three men tried the lamps, it is hard to say. One thing is certain—they were not commercially successful.

The first really successful mercury lamp was made and described in 1892 by Arons, the German physicist. He made little U-lamps very much in the same way as Rapieff describes them. (By the way, I do not think that he knew anything about Rapieff's patent or any of the earlier ones.) Those little U-lamps were filled with mercury, and he makes a particular point that the air above the mercury must be exhausted very carefully. He found very soon that that was one of the most important things to observe for obtaining a good mercury light, to have an extremely good vacuum. The mercury vapor formed inside must be quite free from other gases. Arons goes into detail into the question of the color of the spectrum of the mercury. Furthermore, he determined the efficiency of the mercury are obtained in this way and he found it to be far superior to any other artificial light source. He made rather exhaustive experiments to determine the influence of the length of the gas column on the voltage, and found the law to be fairly simple. Arons did not succeed in making a lamp that could be run with little ballast or no ballast resistance. His lamps had to be run with 40, 60, 70 and 80 per cent. ballast resistance if he wanted to keep them running at all. This, of course, spoiled the extremely high efficiency that the lamp has in itself, commercially, because so large a per cent. of the energy is absorbed in the ballast. Arons did not appreciate fully all the important influences governing the electrical characteristics, especially the conductivity of the vapor. He could make the lamps satisfactory only by absorbing in water the heat developed by the lamp. The lamps which were on the market for spectroscopic work were those U-lamps, as described, in a box with running water. It is natural that such a lamp would not be satisfactory for illuminating purposes. One had first to understand clearly which were the factors governing the electrical characteristics, especially the conductivity of the vapor, before one could begin to construct a serviceable lamp.

This is the point at which Cooper Hewitt stepped in. Hewitt's investigations in this direction are really pioneer work in the field of the mercury lamp and of vapor lamps generally; not only because he taught us how to make the most serviceable illuminating lamps, but also because his research in this line opened up entirely new applications of vapor electrical apparatus, the importance of which may be enormous for the advance of electrophysics and particularly for the advance of our electrical industry. What Hewitt has taught us in regard to the lamp proper may briefly be stated as follows: To obtain a lamp of the desired characteristic, the radiating power of the lamp must be correlated to the energy spent inside the lamp in such a way as to obtain inside, in the gas, the most favorable temperature or density conditions for the efficient generation of light. This controlling of the temperature and density inside the lamp is done by Hewitt in a properly rated condensing chamber outside the light-giving column. In the lamps shown here you see the bulbs are sealed on. The mercury condenses in those bulbs and keeps the density down to the desired point. It is extremely important—and Hewitt has done an enormous amount of work on that—to get the right ratio between the size of the condensing chamber and the size of the tube and the current which one wants to pass through the tube. I do not know whether you remember from the paper which Hewitt published some time ago, the strange characteristic curve of the Hewitt lamp. The curve looks something like this (indicating). If this axis represents the voltage, the horizontal axis represents the amperes. The characteristic voltage curve, with increasing amperes is something like this (indicating); then it rises steeper. The point at which we want the lamp to run is just before it bends up. This point (indicating) represents the most efficient temperature of the mercury vapor for the generation of light. If one runs it on the down part of the curve, the lamp is not so efficient as on the knee. If one runs it on the rising part of the curve the lamp becomes extremely inefficient. If one allows a rise of voltage up to, say, 50 per cent. of the normal voltage, the efficiency of the lamp, which is about .3 to .4 watts per candle, spherically, goes down to .8 or .9 watts per candle.

Hewitt has brought forward the importance of discriminating three capital points in respect to the conductivity of the electric currents in cases generally. The first point is, *positive electrode resistance;* second, *resistance of the gas current proper;* third, *the negative electrode resistance.* The last is the most important. In the ordinary vacuum tubes such as Geisler tubes and similar apparatus, we find that they have an extremely high resistance. This is due, practically, entirely to the extremely high resistance of the negative electrode. If we want to give them a low resistance we must have absolutely a negative electrode of low resistance. Such a low negative electrode resistance is obtainable, according to Hewitt's definition, by using an electrode which the current keeps in disintegrating, boiling or similarly changing condition. Therefore, if we want to make a lamp with low resistance we have to put in, as negative electrode, a disintegrating electrode. We can bring such an electrode to disintegration either by connecting it with the positive and separating it after that, or else by forcing a high potential through it. A high potential of several thousand volts will break through, make the electrode disintegrating, and then the low line potential, which may be attached to this electrode, will follow. Mercury itself is the best material to be used for such disintegrating electrode, because the mercury which disintegrates steams away from the surface, condenses again on the walls of the tube, runs back to the negative, and the negative is again like a new one. Physically expressed, we see that the mercury has an extremely high starting but a very low running potential. The starting potential—the break-through potential, I may call it, for the mercury—is a good many thousand volts, perhaps 6,000 to 8,000, in some cases 15,000 or 30,000 volts; whilst the running potential, that is, the drop across the electrode in a burning lamp, like one of these, is only about five. Once the lamp has been made conductive by means of the break-through of the dielectric on the surface of the negative—that means, when one has brought the negative to a disintegrating state—the lamp conducts extremely well. As soon as the current is interrupted, in the fraction of a second, perhaps the hundred-thousandth of a second, the conductivity of this lamp will cease. If you put the lamp out, and right after doing so put the line potential on again, the lamp will not start again. I can be as quick as I like in making the connection again, you will not see the lamp start. We have first to break through the negative electrode resistance and make the negative electrode disintegrating to get the lamp to run.

On the fact that such a mercury electrode has a very high discharge and a very low running potential, and, furthermore, on the fact that the lamp loses its conductivity practically right away after the current has stopped passing through, Hewitt has based the application of the lamp as a breaker for high-frequency work. You may perhaps remember from the publications that he has applied a lamp shaped something like that large bulb with two electrodes for generating high frequency for, say, wireless telegraphy or similar applications.

If we start the current in the lamp by making the electrode disintegrating, we will naturally believe that the current will go through such a disintegrating electrode only in one way. The disintegrating electrode has to be negative. We may say, although that is not usual, that a current will go from that disintegrating electrode in the tube up to the positive. What we can do with such a lamp, which allows the current to go through only in one way, Mr. Thomas will describe later on to you. It is natural, if you put an alternating current on the two electrodes of one of those lamps, that you have to put on a very high potential to get the first phase through. Now, as soon as that phase is through, the lamp has to be started in the other direction. That means putting a high potential on again. Then that phase is over and the next phase comes again; we will have to start again by means of a high potential, and so on. That will mean practically running the lamp at all times on a very high starting potential to get three amperes through, as we have here. On one of those lamps with alternating current we will have to apply perhaps 5,000 or 6,000 volts, while here these lamps are running on volt-120 direct current.

A few more words about the Hewitt lamp itself and its different applications. I may start by giving just a brief description of the lamp. The lamp consists of glass tubes to which is sealed the condensing chamber. Into the glass tube we lead the current through platinum wires sealed into the tube. As negative electrode we always use mercury; as positive we use either another mercury puddle or any other metal, like iron, copper or similar material. The temperature of the lamp outside is not very high, just about like that of an over-running incandescent lamp. For starting we use this kind of apparatus (indicating). We have our 120-volt direct current coming in here. One line goes through two coils, with about 2,000 turns on an iron wire core. From that coil the line goes through those two little regulating resistances to the lamp. The other pole goes directly to the lamp. The lamp itself can be short-circuited by means of a small resistance, and this switch (indicating), which is a very fast break under oil. If we put the line potential on this starter nothing happens. If we press this handle down the current flows through those coils. You can see that when I open this switch (indicating)—now, the current flows through here and magnetizes those coils. As soon as I let go, a very fast trigger-break occurs in here under oil, and in that way the high potential generated starts the lamp. With this arrangement we can get very high potentials, five and more thousands of volts. We can run two lamps in series on double voltage, or more lamps on a fitting voltage. If we want to make 50-volt lamps, we make them about half as long as the 100-volt lamps. If we want to make lamps for small current we take a smaller diameter. The tubes can be bent in any shape, U-shape or otherwise, as long as it is not too much trouble for the glass blower—and those troubles begin very soon.

When we started to work on the Hewitt lamp we had great hopes regarding its application for different purposes, and I must say that our hopes have been fully realized. The lamp is extremely actinic. That is, it is very rich in photographic active rays, and the Hewitt lamp has proved itself to be an extremely useful and reliable illuminant for the photographic trade. People have for some time used this lamp successfully, using only the low current of three amperes, where they formerly had to use a high current, such as 25 to 50 amperes, with arc lamps; and they get better results with this because the light is so evenly distributed all over the tube. This, of course, refers mainly to its use by photo-engravers and people who do printing, such as blue printing or portrait printing. But the light is also an excellent equivalent for daylight according to the opinion of the best photographic experts. Some of the best photographers in New York have taken pictures by the light of three or four or five lamps, and they say they cannot detect the slightest difference as against pictures taken by daylight, and, of course, they appreciate the advantage of having the lamp always handy, whereas the light they get from outside is not always there when they want it.

Another application is in the hands of physicians, who have taken a great interest in the lamp and are making many experiments, as they expect great healing effects on certain diseases from the actinic rays which are sent out by the lamp. The lamp practically lacks red rays, by reason of which physicians find they can discriminate between certain kinds of inflammations very much better than by daylight, which is so rich in red rays.

The most gratifying for us is the fulfilment of our hopes regarding the lamp as a light source for general illumination where it is important to get the cheapest possible light, where the true ratio of color values is not of importance. We knew, and find it confirmed daily by users, that the total absence of the red rays gives a light which does not fatigue the eye. We also have made actual experiments (although I must say the measurements are only qualitatively reliable), which have shown a distinct superiority of this light which does not have any red rays, over any other illuminant as to the fatigue it produces upon the eye. It is, therefore, a splendid illuminant for places where fine mechanical work, fine jeweler's work, or reading, writing, and especially draughting, is done. We think, therefore, we are justified in saying that the Hewitt light may be of the greatest benefit to mankind.

PRESIDENT SCOTT:—A very notable occasion in the history of the Institute was two years ago this last spring when a conversazione was held at Columbia University in New York. At that time, I believe, was given before this Institute the first public exhibition of the light which we have before us to-night. Mr. Thomas will now give us an exhibition for the first time in public and an explanation of a single-phase vapor lamp. He will also give the first public exhibition of an alternating current vapor circuit breaker.

I have the pleasure of introducing Mr. P. H. Thomas.

MR. THOMAS:—Dr. von Recklinghausen has given you a full description of the Hewitt mercury vapor lamp burning upon direct current, and has described the principles upon which its operation depends. I think most people are in the habit of looking at this invention of Mr. Hewitt's as a new method of getting light. I would like to revise this view. What Mr. Hewitt has really done is to study out the phenomena involved in this manner of getting electricity through a vacuum. It is not a lamp, except incidentally. It is really a new group of phenomena, a new branch of physics, almost. I do not mean to say that he first observed the phenomena, but he is the first man who has worked them out in such a way that they can have commercial applications.

Looking at the operation of the lamp as an experiment in physics we find a number of very curious phenomena developed. Dr. von Recklinghausen has spoken of most of them Looking at it as a means of doing useful work, we see a number of interesting applications.

The first application to be developed commercially is the direct-current lamp. The second, which is now being developed, is the vapor converter, shown so far only as a three-phase converter. The third is the vapor interrupter, or more properly, the vapor discharge gap. and, in addition there are some new applications to be shown to-night.

Perhaps I had better summarize again the peculiar characteristics of this apparatus of Mr. Hewitt's. Strictly, Mr. Hewitt's work has been the study of the phenomena and the laws governing the passage of electricity at low voltage through a high vacuum. As has been already explained, to accomplish this result commercially and operate with low voltages, it is necessary to use for the negative electrode some electrode material like mercury, something which is easily disintegrating, if you please, and also reconstructing.. The most striking phenomena of all is the behavior of the negative electrode resistance. Nothing like it, as far as I know, is found anywhere else. At first, if you attempt to pass a current through the lamp, you meet with very great resistance or reluctance located at the negative electrode. Once you start the current by overcoming this reluctance, as can be done in a number of ways, which will be taken up later, it continues to flow with a loss of voltage perhaps as low as 10 volts, until the current is interrupted or reversed. This abrupt reduction of reluctance is remarkable, perhaps from 30,000 volts to 10 volts in extreme cases. Strangely, the positive electrode, which by convention is taken to be supplying the current, has very little electrode resistance or reluctance. The positive has, apparently, no reluctance to starting and causes little loss of voltage when running. The two electrodes taken together cause from 11 to 15 volts or more loss when running, according to conditions. These running losses are very hard to apportion between positive and negative electrodes. In addition to the two electrode losses, we have in the lamp the resistance of the vapor. This is an extremely complex phenomenon, and nobody, except Mr.

Hewitt, as far as I know, has had any clue at all to the laws governing it; but he has successfully worked out practically all the conditions, at least as far as the range of conditions bearing on his lamp is concerned. This vapor resistance is a most peculiar thing. I will not attempt to state the laws governing it; this would take a whole paper in itself. I will state, however, that in the lamp the principal part of the total voltage is taken up in the vapor column. This is the light-giving portion of the lamp, and for high efficiency it should, of course, consume a large part of the energy. In the vapor converter the light plays no important part, and the vapor path is purposely made very short and very wide, so that little or no voltage is lost there. Therefore, a vapor converter may be made to run with from 10 to 15 volts total loss. A peculiar thing about these negative electrodes and positive electrode resistances is the fact that, other conditions being unaltered, they are practically independent of current. One hundred and fifty amperes will give the same voltage loss as three or four amperes. I must qualify this statement with one exception. If the current drops below three amperes or so this voltage loss does not fall, as perhaps you would expect, but rises very rapidly, and rises to a very high value, sometimes to several hundred volts at .1 ampere.

For the purpose of clearness and definiteness the general type of apparatus under discussion is spoken of as a "vapor conductor," that is a device which carries current by means of mercury or other vapor. The lamp is spoken of as a "vapor lamp"; the converter, as a "vapor converter," and the circuit-breaker, of which I am to speak later, as the "vapor circuit-breaker." This nomenclature will distinguish the various applications from one another and from other types of apparatus performing the same function.

Next, I will describe briefly the operation of the three-phase converter for the benefit of those who may not perhaps understand it. Then I will describe and operate a single-phase vapor converter, a single-phase alternating current vapor lamp and an alternating current vapor circuit-breaker.

The principle underlying the three-phase converter, as already stated, is this negative electrode resistance. As Dr. von Recklinghausen has told you, if you attempt to pass alternating current through an exhausted globe with electrodes or any vapor conductor, after applying the necessary means to start it, the current will continue to flow for one alternation, and then, as it becomes zero preparatory to reversing, this electrode resistance is formed again and everything stops. But suppose we take three transformers, or three sources of potential connected in star with a three-phase relation, as shown in figure 1; suppose we connect the neutral point to the negative electrode marked D in this figure, and each of the three free ends of the transformers to the other three electrodes which are positive. On account of the three-phase relation, it is evident that at all times one of those three positive electrodes, A, B, or C, will be positive with regard to the negative electrode D. Suppose now, by the application of high potential or other suitable means, we start the current flowing at any time, we will say, for instance, when the electrode A is positive. A immediately starts to supply current to the negative electrode D, which current passes around back through any load we may choose to put on the apparatus, to the neutral point of the transformer. As the voltage begins to drop off this current tends to drop off, and if there were no other electrodes would soon become zero; but on account of the three-phase relation the electrode B reaches a positive voltage before the electrode A loses its positive voltage. As a result, current will start to flow from B before it ceases to flow from A. Consequently the electrode D, the negative, at no time ceases to pass current. Similarly, as the electrode B begins to experience a falling voltage, the electrode C has a positive voltage again and takes up the current. By the time C is losing its positive e.m.f., A has gone through the negative cycle and has again become positive and will in its turn take up the current a second time, and so on indefinitely; and this apparatus works just as simply as described. If, however, at any time you open the circuit leading to either A, B or C, the converter will stop. This experiment has been shown a number of times

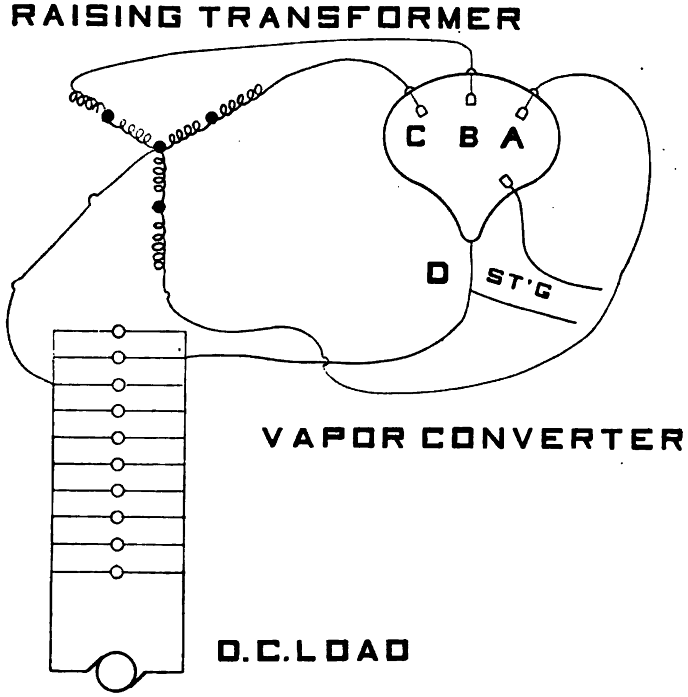


FIG. 1.

When operating as described; the loss of voltage on the useful current, that is the loss of voltage between the negative electrode D and the particular positive electrode which is supplying current, will be 10 to 14 volts. The voltage between D and the other positive electrodes will be very much higher but negative, and as they are supplying no current there is no loss of energy. To explain a little further, consider figure 2. The full lines are supposed to represent the three-phase alternating e.m.f's. You see they differ by 120 degrees. As already explained, each one of the positive electrodes, A, B and C, carries the current for one-third of the period. We will say, during the first period, that the electrode A is carrying the current. At this time the voltage of transformer A is impressed between the neutral point of the transformers and the electrode within the chamber. It is divided into two parts; one part of, say, 14 or 15 volts in the converter, and the rest upon the load. That is to say, if we subtract in the figure the portion between the lines for the loss in the converter, we have the shaded portion representing the voltage which is impressed upon the load. Similarly during the second third of the period we have the energy supplied by B, the second positive electrode, and similarly a slight loss, and the remaining voltage, shaded, representing the voltage impressed upon the load; and for the third portion of the period, we have C supplying the voltage. As a result we have the lower shaded portion of the figure as the voltage impressed upon the load. This, as you see, is slightly

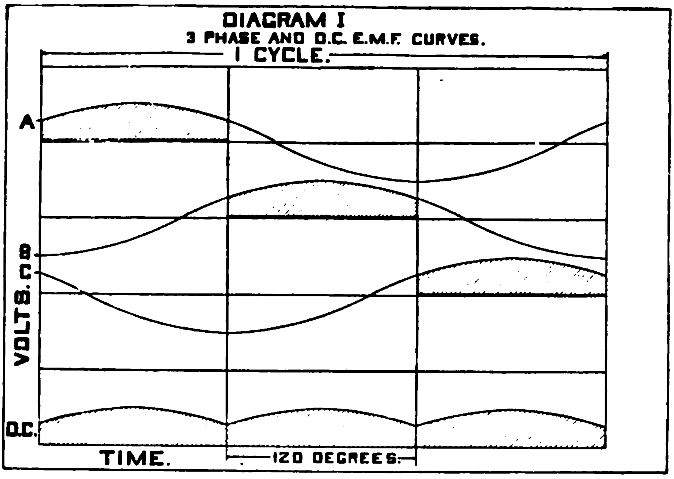


FIG. 2.

wavy, slightly varying. If the load itself contained a large or even a considerable amount of inductance, this waviness would nearly all disappear. For the sake of clearness I have had drawn in Fig. 3 the e.m.f. curve resulting in a non-inductive load circuit from vapor converters of different numbers of phases. Of course, it is evident that if the three-phase converter will operate as shown, a four-phase converter will operate similarly, or a five or six, or any converter with a larger number of phases. Going down one, however, if we attempt to run what I have marked as a two-phase converter, we get into difficulty. I must explain the use of the term two-phase. It is not two-phase in the sense in which the word is usually employed. Two-phase usually means quarter-phase; it means two e.m.f.'s 90 degrees apart. Strictly we ought to speak of two-phase as two opposite phases; at least, we should speak of it that way in connection with vapor converters. So we must understand that two-phase means two e.m.f.'s exactly opposite, 180 degrees apart. If we attempt to run a converter from such a circuit, according to its law, the negative electrode resistance will re-establish itself at the common zero point of the waves and stop the operation of the converter. This result is confirmed by trial. But assuming that the current will continue to flow, we would have an e.m.f. on the direct current circuit something like what is shown in this figure. Of course, there must be 14 volts subtracted for the loss in the converter. In the figure the " ratios " are the ratio of minimum to maximum ordinates of the direct current voltage. It is .5 in the three-phase converter. In the four-phase converter .7 and four phases can be obtained from any of the common two-phase circuits, so-called, by using proper transformers, by reversing phases. In a six-phase converter .86 and six phases can readily be obtained from any three-phase circuit by suitable transformers. Any inductance in the circuit will tend to smooth out these waves. For any commercial purposes probably four or six-phase current is as satisfactory as perfectly steady direct current.

The principle of the single-phase converter depends upon keeping the converter " alive " during the two periods in each cycle during which a converter constructed after the principle of the three-phase converter but with two positives only would go out—by causing the current from either positive to lag behind its e.m.f. until the e.m.f. on the other positive should itself be able to support current. This is easily accomplished by passing the whole or a part of the current through an inductance. Refer to Fig. 3 and suppose one electrode is during its half of the cycle supplying current to an inductive load. The current will build up a little behind the e.m.f. on one positive and when the time in the alternation comes for the latter to fall off will lag behind this e.m.f. But you notice that before that current gets to zero we have a positive e.m.f. on the other positive terminal. The result is that there is no instant during which current is not passing through the negative electrode, so the negative electrode never gets a chance to resume its resistance. As all loads are not inductive, to use this converter on any kind of load an inductive resistance may be put in shunt with the regular load. This shunt circuit will take a certain amount of what you might call leakage current through the negative electrode, keeping it alive at all times, but when, however, much other load is thrown on, there will be no difficulty in taking power from the main circuit.

There are three usual methods of starting lamps and converters. First, as Dr. von Recklinghausen has shown you, the standard commercial starting outfit for the lamp makes use of a high potential from an induction coil, momentarily applied

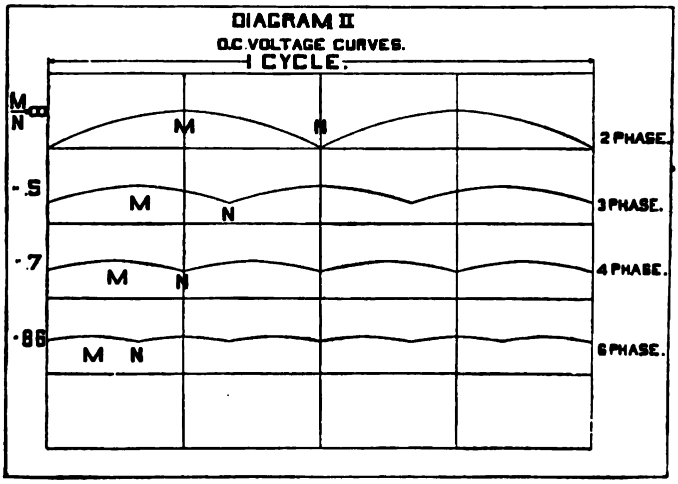


FIG. 3.

to a starting band and to the positive electrode. This high potential is obtained by a quick-break switch. The method can be used to start the vapor converter, but there is one inconvenience about it. The converter runs on alternating current, and the quick-break switch may happen to break the alternating current when it is pretty nearly zero, or it may break it near the maximum, and it is necessary to try a number of times before you hit the wave at the proper point for causing a rise in the potential.

Secondly, the converter may be started by means of a high-tension transformer. If this transformer be excited from the same supply as the converter, the phases of e.m.f. from transformer and converter will keep together, and the e.m.f. will

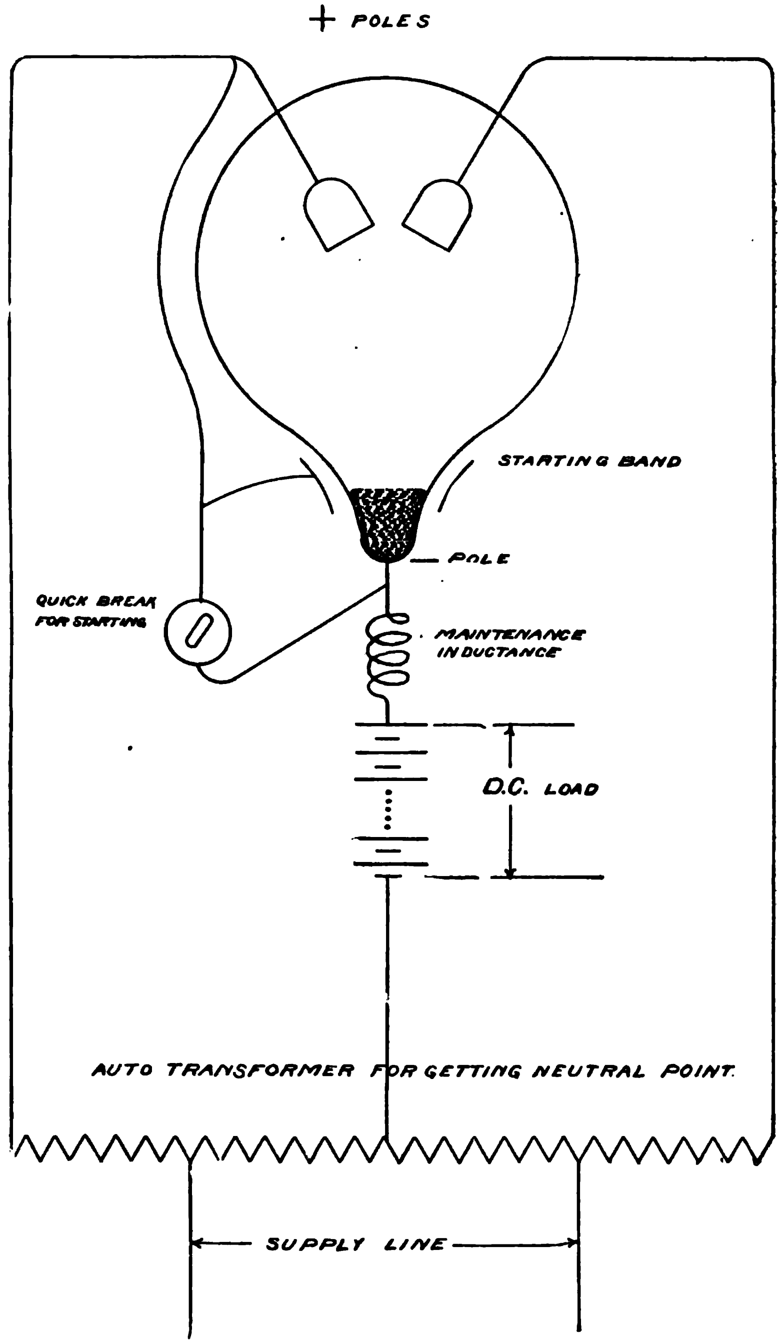

+ POLES
STARTING BAND
POLE
QUICK BREAK FOR STARTING
MAINTENANCE INDUCTANCE
D.C. LOAD
AUTO TRANSFORMER FOR GETTING NEUTRAL POINT.
SUPPLY LINE

Fig. 4.

always be applied at a time when the converter is able to pick up the current.

Thirdly, another method will be shown, the one used by Arons, and for many purposes the simplest. A current is established through the vacuum by forming a closed metallic circuit from the positive to the negative, by causing the mercury or some other metallic conductor to connect the positive and negative. If under such conditions this metallic circuit be opened so that the current has to pass through the vapor; at the instant of separation there is caused somehow or other a breaking down of that negative electrode resistance. That is, the current is not interrupted by breaking the closed metallic circuit within the vacuum. This method eliminates the high potential.

The alternating current lamp is really the same problem as the alternating current converter; but the alternating current lamp, of course, will have no external load to carry. All we need to do is to use two positive electrodes, instead of one, and allow the current from both these positives to pass through the same vapor bath. The result will be a direct current passing steadily through the light-giving portion of the lamp, just as though it were a direct current lamp, only we require two positive electrodes, and we also require the neutral point of the supply system. That neutral point, if it be not available in the supply circuit, may be obtained by means of a small auxiliary transformer. When this lamp is running there is a pulsating direct current, though there is not actually very much pulsation During a single alternation the applied e.m.f. has to do two things It has to maintain the current within the lamp, and it has to supply a little energy in the choke-coil during the increase portion of the pulsation At the time when the zero point is being passed the choke-coil gives back this energy, which during the next alternation has to be restored. Now, if the lamp operate normally, nearly at its minimum voltage, when it is to be started, the lamp during the first alternation of the current must be built up from zero to the maximum point of the variation—not from the minimum point only, as is required after the lamp is once started. This may require three or four times as great an absorption of energy in a given time. It is thus advantageous to supply for the time being an extra potential, which we might call an auxiliary or supplementary potential, to the lamp. This should be discontinued when the lamp has started. This is done in the a.c. lamps shown.

The application of the Hewitt apparatus to the breaking of alternating currents is quite simple. Suppose an attempt is made to pass an alternating current through a lamp. The current goes out at the end of the first alternation. But suppose that by some means the current to be interrupted be made to pass through the lamp. Then when the means used to pass the current be removed the current stops at the first zero point. There are two or three ways of accomplishing this result. One means consists in establishing a mechanical circuit within the vacuum; to carry the current, and then when desired break the mechanical circuit, and the current will go out at the end of the first subsequent alternation, at which time there is no stored magnetic energy and no chance of a rise of potential. A small mercury switch, acting on the principle described, is here shown. It is used to cut out the a. c. lamp. The switch is so constructed that tipping in one direction connects the mercury in the electrodes and tipping in the other separates them, which operation interrupts an alternating current.

This type of circuit-breaker has two or three advantages aside from its ability to open circuits. The first is that the contacts are practically perfect, if mercury be used. In the second place, the contacts will not deteriorate, they will not burn. They do not have to be replaced or carefully adjusted. In the third place, on account of the very short distance which the current needs to be carried in the breaker, it is easy to get a large cross-section of conductor. This makes a very light apparatus, which can consequently be very easily controlled electrically or mechanically or in any other manner. This type has two principal disadvantages: the vacuum must be maintained, and mercury is rather objectionable; but these disadvantages are insignificant in comparison with the advantages to be gained.

Dr. von Recklinghausen and I have shown to-night a number of the applications of this Hewitt apparatus, and have tried to give you some idea of the physical meaning of it. It is a fascinating field, and I trust you will hear again from Mr. Hewitt's inventions before we are through with them.

PRESIDENT SCOTT:—As I have been listening to Mr. Thomas discussing the single-phase relations I have wanted to get my ideas into some form of analogy, into some way of ordinary thinking or acting. I presume Dr. Franklin may have in his mind certain differential equations which give him a perfectly clear idea of just what is going on. I used to have an apparatus that I worked with, and worked with very hard, and it throws some light, to my mind, on this single-phase problem. It was a bicycle. My first bicycle weighed 57 pounds, and on the Pittsburg hills it made a very profound impression, that I remember to this day. This bicycle, of course, was a piece of single-phase apparatus. One pedal went down while the other was coming up—down and up; pullee, pushee; no, it was all pushee, no pullee. (Laughter.) Now, in that respect, as there was no pullee to it, it was like the resistance of the negative electrode. I had to do all the work in one direction, only one end of this single-phase system worked at one time, and the other end at the other time; and as I used to go up hill, my 57 pounds going up grades of 15 per cent. or a little less, I used to go very slowly, and I found it very hard work to get over the dead point. Now Mr. Thomas' current has a very similar trouble—it cannot get over the dead point; and I imagine this evening that if I had had a little apparatus similar to what he has, and could have gotten a little spring under my pedals, something that when

I pushed my foot down as far as I could, would throw it a little farther until I got my other foot just over that dead point, I could have got my wheel over the hills in the same way in which he makes his lamp go. So that I think my experience with the bicycle has helped me to clear up in my mind the difficulty and the ingenious method of overcoming it which are found in the single-phase lamp and the single-phase converter.

Q. (A MEMBER) I should like to ask whether the efficiency of the converter is measured solely by the ratio of 14 to the volts lost to the converter.

A. (MR. THOMAS) That is all the loss there is, except what may occur in the auxiliary apparatus. For instance, if you have an induction coil to keep it alive, that will take a certain amount of energy. There is simply a flood-gate opening, you might say, to allow the current to go out. I ought to have called attention to one thing that inadvertently slipped my mind, in which respect this converter has a great advantage over ordinary converters—the matter of regulation. This 14-volt loss is constant, independent of current. That is, the thing is practically perfect as far as regulation goes. There is really no lost energy there which affects the efficiency.

DR. VON RECKLINGHAUSEN:—On a 120-volt circuit, I have had an over-voltage of 135 volts. That makes the temperature of the lamp run up, and that alters the radiation and the conductivity. The way the lamps are made now they will stand very nicely about 5 or 10 per cent. variation either way; but if it gets up to 15 and 16, something like that, they won't do it. The mercury gets too hot and then we work on the up-going part of the volt-ampere curve. The conductivity of the vapor goes down, the resistance goes up and the lamp has to cool down again before it has its normal conductivity.

Q. Does it go out?

A. It goes out, yes.

Q. It doesn't get brighter then with high voltage?

A. Oh, yes, it gets brighter up to a certain temperature, but getting brighter means also getting hotter. It stands a certain amount, but not over much, just on account of that peculiar volt-ampere characteristic. If the voltage goes down the current drops down some, and if it drops down too much the current goes below the maintaining current. The lamps of this type cannot be run below, well, say, about 1.2 amperes, something like that. The normal amount is three amperes. Apparently there is a certain amount of current necessary to keep the electrode disintegrating. Once that current drops too low down, the negative electrode refuses to disintegrate any more and the current stops flowing.

Q. What voltage does that correspond to, 1.2?

A. On a 120-volt, lamp like this it may correspond to 80 or 90 volts line pressure.

Q. That is considerable of a drop?

A. Oh, yes. That is a drop which will never happen on a commercial line, according to what the central station people say.

Q. For a smaller ampere lamp you use a smaller tube?

A. Yes.

Q. What is the smallest ampere lamp you can make?

A. We have made what I may call toys for about .4 ampere or .3 ampere. They were for about a 100 volt circuit, They were about 70 c.p. They are too small to be made practically. We made a very nice lamp about half the size of this, but below that they are not of advantage. There is no advantage in going too low down.

Q. I would like to ask Dr. von Recklinghausen whether I understood him rightly in the early part of the evening when he said that this lamp would not operate with a trace of any other gas in it.

A. Of course the lamp will stand a trace; that is certain. As a matter of fact, I suppose with the best apparatus at our disposal we will never be able to get out all of the gas, but if we have what I would call more than a trace—it is very hard to determine how much will spoil it—the lamp is of extremely high voltage and is unsatisfactory in every way. It runs very unsatisfactorily, blackens the glass and does all sorts of harm.

Q. Didn't you say you tried to add red to the lamps?

A. Yes, we tried that too. I mentioned in connection with one of the very early patents, mercury lamps in which the inventor proposed to use nitrogen to get a different color.

Q. That was never a commercial success?

A. Oh, no. The colors changed all right; there is no doubt about that.

Q. Would a red reflector give the light a red color?

A. The spectrum has no red, and therefore red glass or a red reflector would act like a gray or black glass or reflector; that means, no reflector. The only possible way of getting red from a source which has no red is fluorescence. I am sorry I did not bring that along. We have made some experiments to get dye stuffs which show fluorescence under the influence of certain mercury light waves; that is, which transform certain waves that the mercury light has into red waves. Rhodamin is one of those dye stuffs. If we have a piece of silk round the lamp, then the lamp looks distinctly red and people look a good deal more human than they do without it.

Q. It is very essential that the mercury should be very pure, is it not?

A. So long as the mercury does not contain gas it does not matter. We can use amalgams, but there are all sorts of troubles coming in—attack of the glass and that sort of thing; and then it is extermely difficult to get the gas out of an amalgam.

Q. This question is asked, whether the life is like that of incandescent lamps, say, 800 hours.

A. Well, without promising in every case, we can say that the lamps will surely live a thousand hours. Since we have really known how to make them; that is, since we know every trick of the new trade, practically no lamp has given out at all under 2000 hours. The candle power seems to drop slightly, due to a slight coloring of the glass. It will drop the candle power 10 per cent. or so. The life seems to be terminated by the vacuum getting bad. There must be some place where the air does leak into the lamp. It is highly improbable that it leaks in through the glass. In all probability it goes lengthwise through the platinum wire that is sealed into the glass. The lamp is put on to the pump again, pumped out, and is then like a new lamp. There is no consumption of the mercury. The mercury and the vapor is entirely enclosed, and the mercury electrode reconstructs itself all the time.

Q. Is the amount of light even all over the tube after it has been burning a few hundred hours?

A. Yes, it seems to be absolutely even all over I may say, speaking of candle power—it is of course an extremely hard thing to determine the candle power of a light the color of which is so very different from any of our yellowish standards—all our standards have a very yellowish color. Our photometer measurements I should not call more exact than within 10 per cent. Of course, we check them up with reading tests with standardized incandescent lamps, but still there is a good deal of doubt about them. The candle power of one of these is about 700 c.p. The ballast resistance is those two coils and those two little regulating rheostats. It is necessary to have it with this type of lamp. If we arrange the condensing chamber and the amperes of the lamp differently, then we can use less ballast; but we run into difficulties of a different kind, as to variation of pressure and so on. We have made lamps with about half the present ballast resistances, but they were not quite as satisfactory in other ways. The whole problem of the condensing chamber, the density and those things, is an extremely difficult one. The lowest voltage for which a lamp can be constructed would be the voltage of the converter; that would be 15 volts. That would be a lamp that gave no light; and any volts in excess would give a corresponding amount of light. If you make a 20-volt lamp, for instance, the 15 volts would be consumed in the electrodes and not give any light, and the five volts remaining would give light; of course this would not be efficient. The longer we make the lamps the more efficient they get, because the energy absorbed in the electrodes becomes a smaller percentage with high voltages than with low voltage lamps. The current at the beginning is somewhat higher than afterwards. I should say that a lamp of this type will take perhaps 4½ or five amperes for a few seconds, and gradually to work down to three amperes in five or ten seconds. For each lamp or each series of lamps we have a separate starting device. For instance, if we had 240 volts, we would have two lamps in series on one starting device. We have 15 volts in the electrodes, and about 20 volts in the ballast; that makes 35 out of 120. I should say 65 per cent. gives light and the rest does electrode work or ballast work.

Q. I would like to ask a question about this peculiar characteristic curve. As I understand it, one voltage will correspond to two amperages. If certain voltage is impressed on the lamp, what determines whether the higher or the lower current flows through?

A. The lamp will go to the low ampere 90-volt point if we do not allow enough current to pass through it. It will go to the high current 90-volt point if we allow enough current to pass through it.

Q. But if the moment that the high tension is taken off is the moment you put on the current, will it simply go to the high current part of the curve?

A. That depends entirely on the ballast resistance you have. If your ballast resistance allows too many amperes, say the necessary four amperes or so, to pass through, then it will naturally go to the high ampere 90-volt point. If you allow only one ampere to go through, it will go to the low ampere 90-volt point; and wherever it goes on that inner upper end of the curve, it is in a very unstable state; the lamp is always very near going out.

There are some other phenomena connected with the lamp which we could not speak about to-night, because they are pretty hard to demonstrate with the apparatus we have here. For instance, just at the negative electrode there is a long pinkish flame shooting off from the surface, absolutely independent of the real light-giving gas column; that flame in a properly constructed lamp may be two or three feet long, and has very peculiar properties under the influence of a magnet and so on.

Q. Well, I am reminded in that connection of that theory of Drude's that the escape of electricity from metal is due to the ionization of the metal and the giving off of a vapor consisting of ions. If that is true, there must be some sort of a cathode ray effect; and you say you have not detected any sort of a cathode ray?

A. It may be cathode ray effect, but in the way one detects cathode rays we have never detected or found any.

Mr. C. O. Mailloux:—I would like to ask Mr. Thomas some questions regarding the commercial possibilities of the vapor converter. I would like to know, for instance, what is the largest that has been made thus far, and whether, in case a large output were required, it would be possible to group these little glass balls in various ways, so as to obtain a large resultant total effect. In other words, may we look forward to a time, in the near future, when we can operate a vapor converter giving the same effect as the ordinary rotary converter, of several hundreds, perhaps several thousands, kilowatt capacity? I also would like some idea of the possible cost, I should perhaps say the great drop in cost, that would result from the introduction of this wonderful invention. I may say we are all prepared to expect that the cost per k.w. will be very low.

MR. THOMAS:—There are very good prospects that in the end the improved vapor converter can be used for railway work. Of course, you cannot get any converters for that purpose now. Mr. Westinghouse is having the matter taken up in a very broad manner, with a view of ultimate speed rather than immediate results; and the different phenomena involved, the different problems, of which you can see there are a great many, are being investigated separately and individually and no effort has been made to assemble a single converter of the maximum capacity. The total k.w. that can be obtained from a vapor converter of this type is determined by the current that can be transmitted without undue heating and the generator voltage that is used, which voltage is determined by other considerations than the requirements of the converter itself. The converter within limits is not affected by the generator voltage. It is expected that they will be operated in groups if necessary, but there is good reason to hope it will not be necessary to group them.

Q. Suppose, due to some cause or other, the current were increased to 200 instead of 100 amperes, what would be the result?

A. I can illustrate. By accident here I just now crossed the two positive electrodes when I was starting the experiment. Nothing happened except the blowing of two small fuses. There was a dead short circuit through those fuses. You didn't know that anything had happened. If there were no fuses, the result would depend upon how the converter is designed. Nothing peculiar happens, unless the short circuit be very excessive. It doesn't affect the vapor injuriously. The chief difficulty is where the metal leads in through the glass. If the metal expands enough it will crack the glass. Well, to take this particular converter, as it stands, the difficulty limiting the capacity would be the heating up of the globe. If you put it under oil we might heat the platinum at the bottom so much that it would swell and break the glass at the seal. If you dissipate the heat the capacity of the device goes on up. There is no one limiting factor that we have found so far. The heating is proportional to the current, not to the square of the current. This gives the advantage that there is no variation of voltage due to change of current—therefore the regulation is perfect.

Q. With a fluctuating load will the device operate successfully or will the phenomena of a rise of resistance from overload, as seen in the lamp, cause trouble?

A. Well, the conditions between lamp and converter are very different. The lamp is designed to run taking all the voltage of the circuit. The converter only takes a small fraction of the voltage of the circuit, and you have all the remaining voltage forcing the current through in case of temporary excess of demand.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 30, 1903.

HIGH-SPEED ELECTRIC RAILWAY PROBLEMS.

BY A. H. ARMSTRONG.

Among the many questions to be considered in a new railway project, perhaps the one of primary importance is the question of the proper speed at which to *operate*, as depending upon this factor is not only the first cost of the road, but its cost of operation and probable receipts. It is the purpose of this paper to touch briefly upon some of the fundamental relations existing between first cost of a railway system, its probable cost of operation and schedule speed, discussing also the probable traffic receipts to be secured with different methods of operation. In considering so broad a problem in a paper of this length, it will be necessary to omit detailed proof of many of the statements made, but the method of arriving at the conclusions will be outlined. Most of the data presented are obtained from a very elaborate series of experimental tests, so that the results obtained may be considered of direct practical application.

Owing to the wide field covered by the electric railway motor, it is not possible to consider all classes of railways and therefore this discussion is limited to the relatively high-speed roads. It is a mistaken idea that acceleration problems are met with only in city or elevated work where the stops are frequent. Although the so-called high-speed roads stop at comparatively infrequent intervals, the relation existing between stops and schedule speeds often calls for the most serious consideration of fractional speed-running of the motors. Such roads really act as tributaries to large city street railway systems and must be able to operate over several miles of city tracks at slow schedule and with frequent stops, and also be adapted for operation at 40 or 50 m.p.h., with infrequent stops on a private right of way.

While each road presents its own local characteristics they can generally be divided into two broad classes, those having frequent stops and those having very few stops. Both classes of service will probably parallel one or more steam lines and must make a schedule speed that will compare favorably with that obtaining on the competing steam road. This high schedule speed must also be made with more frequent stops than given by the steam service, and in nearly all cases over a track which has many sharp curves, which have the effect of still further increasing the number of stops. Interurban roads having very infrequent stops, say one stop in five or ten miles, private right of way, and an alignment free from curves of less than three degrees, can give a service equal or superior to any competing steam line, and can furthermore provide the frequent service which has proved one of the valuable assets of electric roads. Moreover, the generating station, feeder system, motor capacity, and power consumption will be moderate in first cost. The problem of high-speed electric service therefore is comparatively simple, provided the alignment is free from sharp curves and the stops are very infrequent, and such a service can be operated at a less cost and will attract more traffic than the competing steam line with its antiquated method of operating with steam locomotives.

Suburban roads, however, that pick up their load at frequent intervals along the route and still have to compete with parallel steam lines, present problems much more difficult to solve from an economic standpoint. It is the custom of such roads to establish stopping points, say one mile or less apart, and stop at these points only on signal. During certain portions of the day, however, cars will be obliged to stop at nearly all these stations, and will either fall behind their schedule at such times or will have too much leeway during the remainder of the day when stops are much less frequent. Moreover, owing to the considerable city running at necessarily slow speeds, these suburban roads must make as good time as possible on the suburban route in order to bring the passengers from the more distant points within a reasonable time, including city running. In fact, such roads when paralleling steam lines operating on private right of way through the city, and moreover giving excellent service morning and night to commuters, are compelled to face very serious engineering and economic problems due to the tremendous amount of generating apparatus, line-copper and motive power required to give equally good service.

A suburban road will develop a considerable amount of traffic, due to its frequent service, but there comes a time when such roads will extend beyond the zone of half hour runs into the city and try to reach the outlying districts hitherto belonging exclusively to the steam lines. The frequent service will always be a valuable asset and one that cannot be duplicated with the steam locomotive, except at higher cost of operation; but if it takes considerably longer to reach the city by means of the electric line than by the steam road with its better facilities for high speed, the electric line will fail to obtain the proportion of suburban business to which it has been accustomed in its more limited scope. In other words, it fails in its purpose, due to the frequent stops to which its previous popularity was due.

In considering the proper speed at which to operate a new electric line, it is necessary therefore to go very carefully into local details and especially canvass the competition with existing steam lines not only when operated in their present form, but also consider the possibility of their adopting electricity as a motive power.

In considering the possible speeds of a car or train of cars, the investigator is met with the necessity of obtaining some accurate data on the question of car and train friction. The greater part of the data now existing on this subject have been obtained with trains hauled by steam locomotives. Many of these results were obtained by draw-bar pull and hence neglected the wind-friction of the locomotive, and those taken by indicator diagrams are open to the objection that the steam locomotive is not square ended like a car and wind-friction results so obtained are not applicable to the operation of the train electrically without locomotive. Moreover, all these results were obtained with more than a single car in the train and do not apply to suburban electrical operation which almost universally uses single-car trains. Tests are being made from time to time with electrically operated trains, and due to the refinement of the carefully calibrated voltmeter and ammeter it is possible to obtain wind-friction values at various speeds and with different number of cars in a train with greater accuracy than in the previous steam tests. These results are not at all complete and the only attempt known to the writer to obtain friction values with different number of cars was made by W. J. Davis, Jr., through the courtesy of the International Railway Company on its Buffalo & Lockport line in March, 1900 Using these tests as a basis, the writer has drawn up three friction curves in Fig. 1, designating them A, B and C.

The C curve will hold approximately for single-car operation where the car weighs in the vicinity of 40 tons. The B-curve applies to the operation of two such cars in a train and the A-curve to a train of such cars, say eight or more in a train. These curves are not published with the idea that they are correct, in fact the speeds at which they were obtained do not exceed 60 m.p.h., and hence extension beyond this speed is based upon a formula which will follow curve shape up to 60 m.p.h. As the results obtained by using them are not dependent upon their

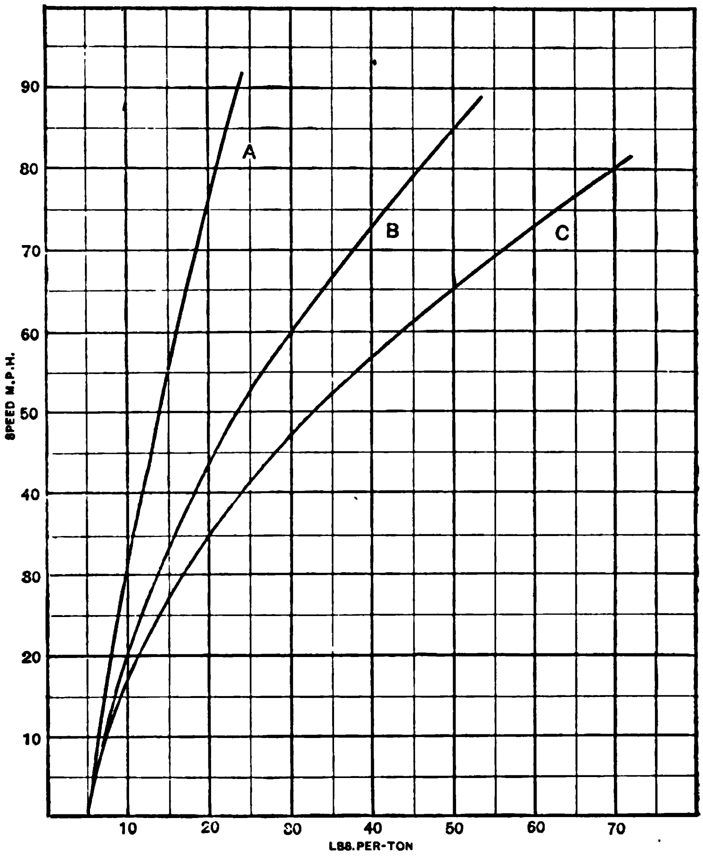


FIG. 1 —Friction Curves.

numerical values, intermediate points being easily interpolated, it is not of prime importance that the three friction-curves given represent accurately the conditions as set forth. In fact, with the different shaped cars now in use and the different cross-section of cars having the same weight, etc., it is hardly possible to make one friction-curve which would apply accurately to all cases. It is probable, however, that the curves given have the general shape and the numerical values applying to average conditions. The friction curves have been extended to maximum speeds approaching 90 m.p.h. in order that questions of motor capacity, train energy, possible schedule speeds, etc., can be followed up to maximum speeds equal to or better than those in vogue on the present steam roads. As will be pointed out later in this paper, the consideration of the proper method of operating a railway service at these high maximum speeds leads to very interesting results as determining the size of trains and frequency of service to be adopted.

With the friction curves in Fig. 1 as a basis, the curves in Figs. 2, 3 and 4 have been calculated, showing the possible schedule speeds and energy consumption required for these speeds up to and including 75 m.p.h. maximum. The method used in making up these curves is similar to that pointed out in a paper entitled A STUDY OF THE HEATING OF RAILWAY MOTORS presented by the writer at the annual meeting of the INSTITUTE in 1902. As indicated in that paper, the rate of acceleration and rate of braking do not have a marked effect on the energy consumption or possible schedule speeds for these comparatively high-speed roads. The shape of the motor characteristic also is not a determining feature and can be neglected without introducing a possible error of more than a few per cent. The controlling factor in all of these curves is the friction-curve, which includes track, rolling, journal, and wind-friction.

The constants assumed in calculating the above curves are those pertaining to average high-speed suburban work as follows:

Gross accelerating rate	120 lbs. per ton
Braking effort (average)	120 " " "
Duration of stop....................	15 seconds each.

Track assumed to be perfectly straight and level.

In the above curves, due consideration is given to all the losses occurring during acceleration with the standard series-parallel controller and direct-current motors. If the curves are to be used for alternating-current motors, allowance must be made for the difference in accelerating efficiency of the two types of motors and their methods of control. The inertia of the rotating parts of the equipment generally amounts to 5 per cent. and this value is taken throughout, being perhaps a little high for the higher speeds and low for the lower speeds. The speed-curve of a standard 125 h.p. motor is used throughout. The energy curves

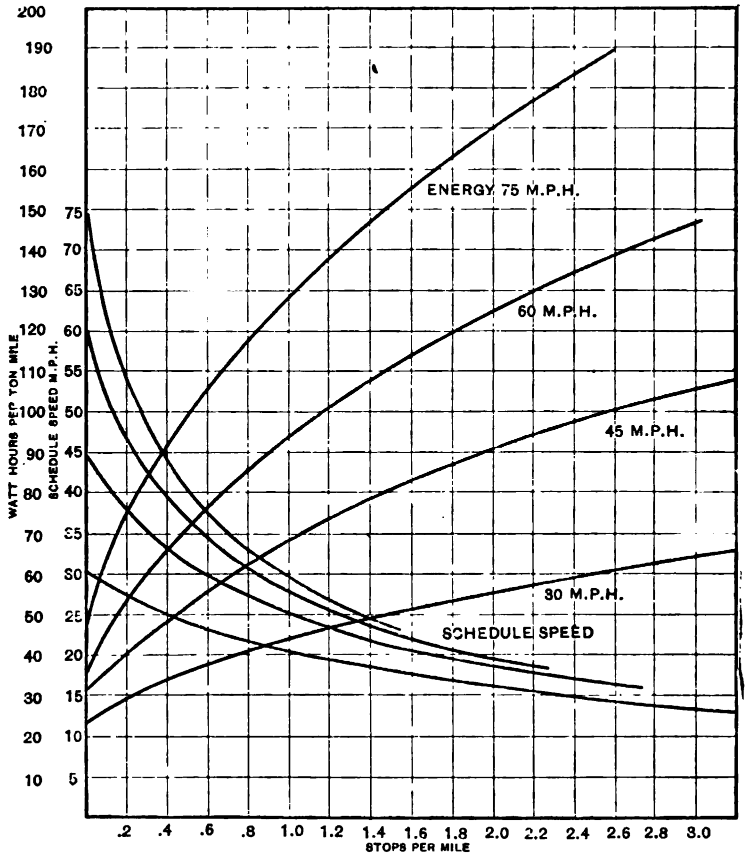


FIG. 2.—Speed and Energy Curves. A. Friction Curve.

given are somewhat affected by the amount of coasting done, although this is not so determining a factor in this high-speed work as it is in slow-speed rapid transit accelerating problems. In order that the energy curves should be conservative, they are plotted with only 10 seconds of coasting permitted and therefore the schedule speeds given are nearly the maximum possible, and the energy curves given are also practically the maximum possible with the maximum speeds assumed. Should power be shut off earlier and more coasting permitted, the energy consumption would have been decreased and the schedule speeds decreased somewhat also, especially with the more frequent stops per mile.

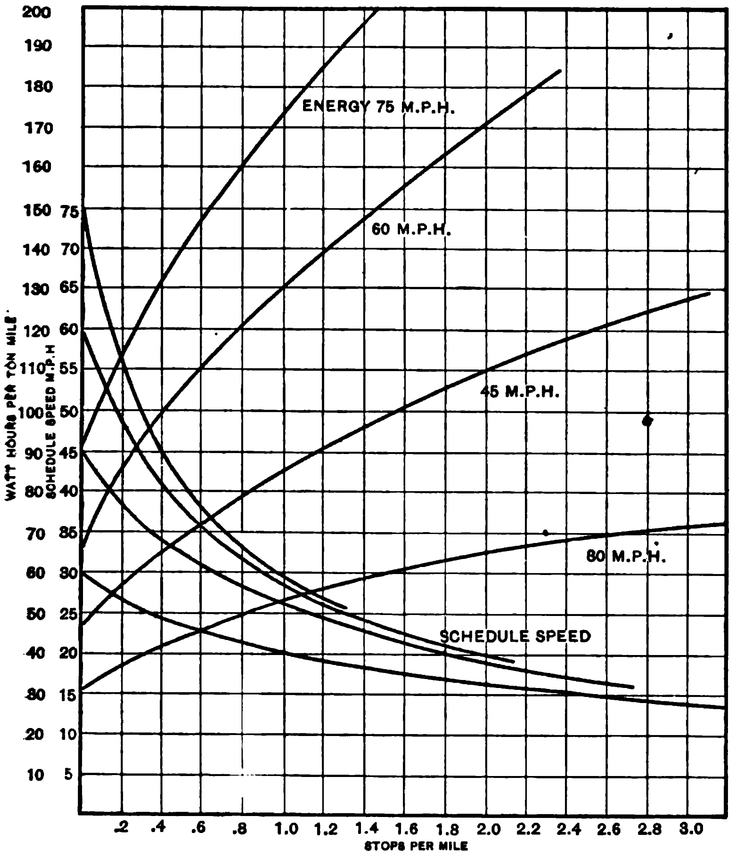


FIG. 3.—Speed and Energy Curves. B. Friction Curve.

An inspection of these three sets of curves will bring out the very great effect of the wind-friction when using trains of one or two cars at very high speeds, in fact at 75 m.p.h. maximum speed the operation of single car trains becomes impracticable with light 40-ton cars of standard construction, and even at 60 m.p.h. is questionable. To quote from the curves, it requires an energy consumption of 47 watt-hours per ton-mile for a train of several cars, as against 137 watt-hours per ton-mile for a single car operating at 75 m.p.h. without stops; that is, a single car operation would demand 3.7 times the energy per ton that would be required for the operation of a train of many similar cars. Even a two-car train will require but 92 watt-hours per ton-mile, or only 67 per cent. of the energy required per ton for single car operation. As these values are for constant-speed running, while more or less frequent stops would obtain, a comparison at say one stop in 4 miles would be nearer the actual results in practice. Here a single car requires 157 watt-hours per ton-mile, a two-car train requires 120 and a train of several cars 79 watt-hours per ton-mile. The results would indicate that in a

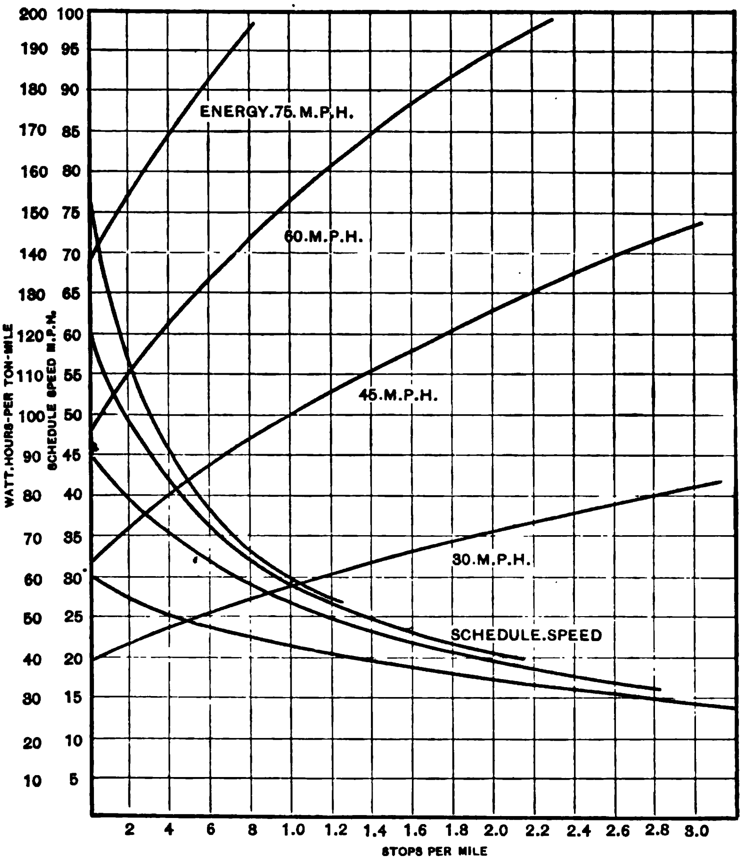


FIG. 4.—Speed and Energy Curves. C. Friction Curve.

class of service calling for very high maximum speeds, the tendency of electric roads will be to follow steam railroad practice and operate trains of several cars at more infrequent intervals rather than follow present practice of suburban electric roads and run single cars at frequent intervals. It will be a question for local consideration whether sufficient additional traffic would be gained by the operation of single cars, say on half hour headway, or trains of two or three cars on one hour headway or more, the latter requiring but 60 or 70 per cent. of the power per ton moved, and also effect a considerable saving in train-crew expenses. As the maximum speed of the service is reduced, the difference in energy consumption between single cars and trains of cars is also reduced and at 30 m.p.h. a single car will require but slightly more energy per ton than a train when operated at the frequent stops characteristic of low-speed service.

Another very interesting feature which is well known but perhaps not fully appreciated is brought out by the curves of schedule speeds possible for different maximum speeds. Thus, with one stop in 8 miles it is possible to make a schedule of 61 m.p.h. with maximum speed of 75 m.p.h., and a schedule of 28 m.p.h. with maximum speed of 30 m.p.h. If stops be increased so that they average one per mile, however, the schedule speed possible with a maximum speed of 75 m.p.h. is dropped to 29 m.p.h., while the 30 m.p.h. maximum speed permits of a schedule speed of 22 m.p.h. Thus while 30 miles is but 40 per cent. of the higher maximum speed it permits a schedule at one stop per mile of 76 per cent. of that possible with 75 m.p.h. maximum speed. The fallacy of using high-speed equipments for frequent stops is forcibly brought out by referring to the energy curves in Figs. 2, 3 and 4. With one stop per mile it requires 200 watt-hours per ton mile with 75 mile maximum speed equipment, and the 30 miles maximum speed equipment can obtain 76 per cent. of the same schedule with an expenditure of only 28.5 per cent. of the energy. The two values taken for the maximum speed are the extreme, but serve the purpose of bringing out the tremendous price paid for high schedule speeds at frequent stops. The conditions of acceleration and braking are the same in both these equipments, while if higher schedule speeds were required with, say, one stop per mile, a higher rate of acceleration and, if practical, a higher rate of braking would be adopted. The difference in energy values would be considerably reduced thereby, but neither the average rate of acceleration nor the braking could be very largely increased without incurring the possibility of discomfort to passengers.

Before considering the application of the previous curves to a concrete case, it is necessary to include the effect of the different friction curves at high speeds upon the capacity of the motor equipment. In the paper by the writer at the last annual meeting of the INSTITUTE, the manner of fully determining the capacity of a motor for any service was indicated. The details of this method will not be gone into in the present paper, but for convenience a sample motor capacity-curve of a 125 h.p. equipment operating at a maximum speed of 45 m.p.h. is shown in Fig. 5.

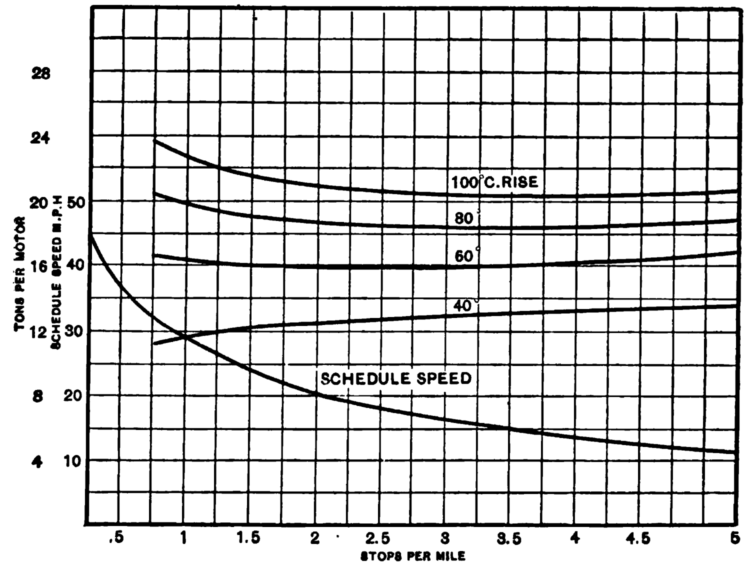


Fig. 5.—Motor Capacity Curves 125 h.p. Motor. B. Friction Curve.

The means taken to determine the capacity of this motor is to obtain from a series of temperature runs made upon an experimental track the degrees rise per watt loss in different parts of the motor for different ratio of losses for armature and field. It is obvious that so long as the motor losses and their distribution are the same, the temperature rise of the different parts of the motor will also be practically the same. This assumes that the car will travel at the same average speed, which is not necessarily the case owing to the fact that the same motor cycle could be obtained with a considerably different train cycle. A service capacity-curve similar to Fig. 5 on the 125 h.p. motor is therefore not absolutely correct unless the thermal capacity curves be obtained from actual tests giving the same train-cycle as that indicated. It is not necessary to conduct so elaborate a series of tests, as a sufficiently close result can be obtained for practical purposes by obtaining the experimental thermal capacity curves at moderate average speeds upon an experimental track, and assuming that the conditions of ventilation so obtained will hold true for all the schedule speeds. It is admitted that a source of error is thus introduced and that motor service capacity curves will read too conservative at the very high speeds and will possibly be too liberal at the lower speeds; but conservatism at speeds approaching 75 m.p.h. could not be criticised as poor engineering, and the results given in following curves are therefore presented with full confidence that they will meet a long felt want and will moreover be approximately correct for types of motors similar to those serving as basis of calculation and experiments.

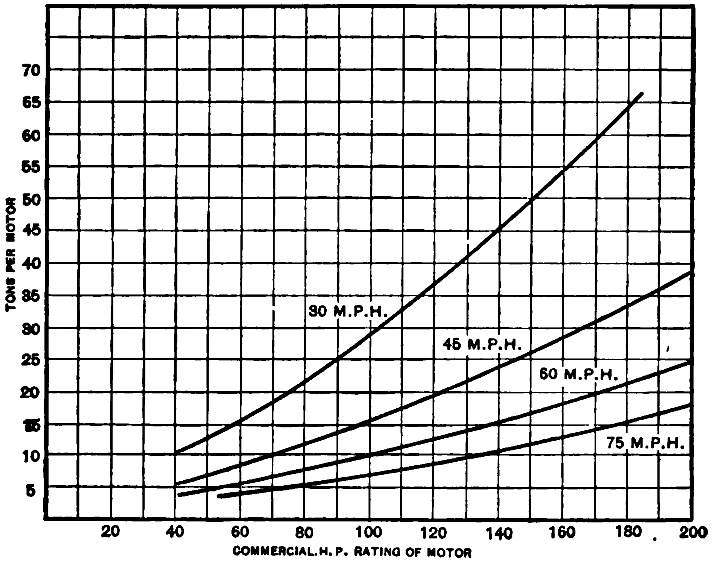


FIG. 6.—Motor Capacity 60° C. Rise. A. Friction Curve.

An inspection of the curves given in Fig. 5 discloses the fact that for a given temperature-rise the capacity in tons per motor is practically a fixed amount. For example, a temperature rise of 60° C. will be obtained with approximately 16.2 tons per motor over a range extending from one stop in four miles to five stops per mile. It is thus sufficient to associate a given motor and gear ratio with a definite car weight which it can operate with a given temperature-rise, and with any schedule speed which the number of stops per mile will permit. This at once affords a means of comparing motors of different capacity by means of the " tons per motor " which is permitted for say 60° rise and a given maximum speed equipment. In presenting the curves in Fig. 6, the results of a large number of experiments and calculations are incorporated on motors of similar design, giving the relation between the commercial one-hour rating of the motor and the number of tons which that motor will carry at maximum speeds of 30, 45, 60 and 75 m.p.h. The curves of 30 and 45 m.p.h. are probably accurate, those at 60 m.p.h. may be open to the criticism of being conservative, and at 75 m.p.h. with the superior ventilation afforded by the schedule speeds incident to such high maximum speeds, the motor-capacity curves perhaps indicate too low a ton weight for 60° rise. As no electric road as yet affords means of obtaining experimental values at this high maximum speed, the degree of error cannot be determined and in any case should not exceed more than a possible maximum of 15 per cent. Figs. 7 and 8 are plotted for 60° also, but using friction curves B and C, so that by means of Figs. 6, 7 and 8 it is possible to determine the capacity of motor required for any maximum speed and any weight of train; while from Figs. 2, 3 and 4, the possible schedule speed and energy consumption can be obtained for any maximum speed and frequency of stops. The maximum speeds of 30, 45, 60 and 75 m.p.h. have been chosen as covering the present field of electric railroading, and intermediate values may be readily interpolated.

The relation between the commercial one-hour rating of a railway motor and its service capacity-performance is very difficult to express. In fact, it is almost impossible to compare two motors differing essentially in their mechanical design, as the stand-test of a motor has no direct bearing on its service performance with its different distribution of losses and better facilities for ventilation. It is necessary therefore to obtain by experiment the performance of each individual motor under conditions approximating service operation, and determine the relation of stand-test to service operation for the particular motor in question. By carrying on a series of exhaustive tests on each individual motor it becomes possible to plot the results of such tests in curve form and show the relation between stand-tests and service capacity, provided motors are of the same general design. Having obtained the capacity in tons per motor for different maximum-speed equipments, the results were all found to follow the general law noted in Fig. 5; that is, the temperature rise was found to be practically constant over a wide range in stops per mile and schedule speed. With this simplification it becomes possible to compile curves 6, 7 and 8, giving the capacity motor required for any train weight, schedule, and frequency of stops, the motors all being of similar design. These curves are all plotted with motors of the closed type, it being assumed that in miscellaneous operation advantage cannot be taken of opening ventilators. Where motors can be operated partially or fully open, the capacity, especially at high speeds, will be considerably increased. It is probable, however, that motors operating at speeds approaching 60 to 70 m.p.h. will be upon a surface track where it would be advisable to protect the motor from dust and moisture, and thus operate closed.

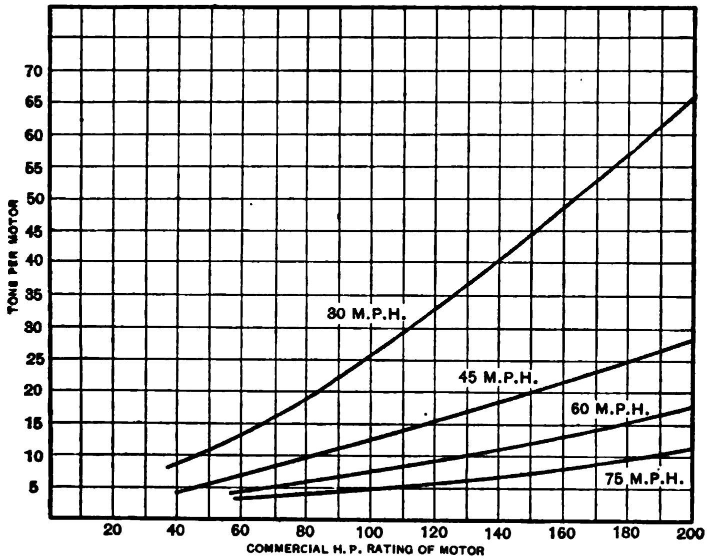


FIG. 7.—Motor Capacity 60° C. Rise. B. Friction Curve.

The results brought out by curves, 6, 7 and 8 are very instructive as determining the probable trend of very high-speed electric railroading where trains of one or more cars are used. For example, a 40 ton car equipped with four motors, thus giving 10 tons per motor, will require a 133 h.p. motor for 60° rise when operating a train of several cars at 75 m.p.h. maximum speed, while the same weight of car would require a motor of at least 230 h.p. if operated as a single car with the same temperature rise and similar design of motor. That is, the motive power is doubled in going from train to single car service. Thus not only is train-friction the determining feature of energy values, but it is the controlling feature as well of the motor capacity required to perform a given high-speed service.

As pointed out in the earlier part of this paper it is not necessary that the friction curves A, B and C shall in themselves correctly give the numerical values for train, single-car and two-car work. The general shape of the curves is undoubtedly that pertaining to their respective size of train, and as the three curves are taken and subsequent calculations are all made upon a three curve friction basis, it is relatively an easy matter to interpolate and obtain the energy, schedule speed and motor capacity required for any train-friction expressed in pounds per ton. The friction curves are of use therefore only in determining the fundamental values of train energy and motor capacity given in the subsequent curves, and the energy, schedule speed, and motor capacity can be obtained from these curves whether the friction pertaining to the case in hand is, say, 33 lbs. per ton at 50 m.p.h. for single car operation, or more or less than this value. The application of the motor and energy curve is therefore universal and it is only necessary to obtain sufficient experimental data of the particular type of car or train proposed to determine accurately its friction for a given maximum speed and obtain the various values required by interpolation in the curves given.

Having obtained the data upon which to base calculations for the proposed electric road, perhaps the best method of showing its application would be to take a concrete case. Let the distance from A to B be, say, 100 miles, or great enough to get over the consideration of location of substations in relation to the length of the line. Assume also that the proposed road will parallel a steam line, or that there are other reasons necessitating a high schedule speed, and that stops will occur every four miles and will be of 15 seconds duration, and that the motors will be direct current supplied from substations fed from a single central generating station. It is desired to know the effect that single car or train operation will have upon first cost and cost of operation.

It is assumed that the competing steam road will have a schedule speed in the vicinity of 40 m.p.h. Such express trains as exceed this schedule will offer such very infrequent service, and will furthermore be so restricted to their through travel that they will not enter as a factor for consideration. By referring to Fig. 4 we find that a schedule speed of 40 m.p.h. can be obtained with a maximum speed of approximately 48 m.p.h. with one stop in four miles. The energy consumption will be 82-watt hours per ton-mile and the motor capacity will consist of four 110 h.p. motors operating a single 40-ton car with a temperature rise of 60° (Fig. 8). The energy consumed at the car will therefore be 131 k.w. or 144 k.w. at the substation bus-bar, allowing an average drop of 10 per cent. in the third rail. With a substation bus-bar potential at 600 volts, each car will average 240 amperes.

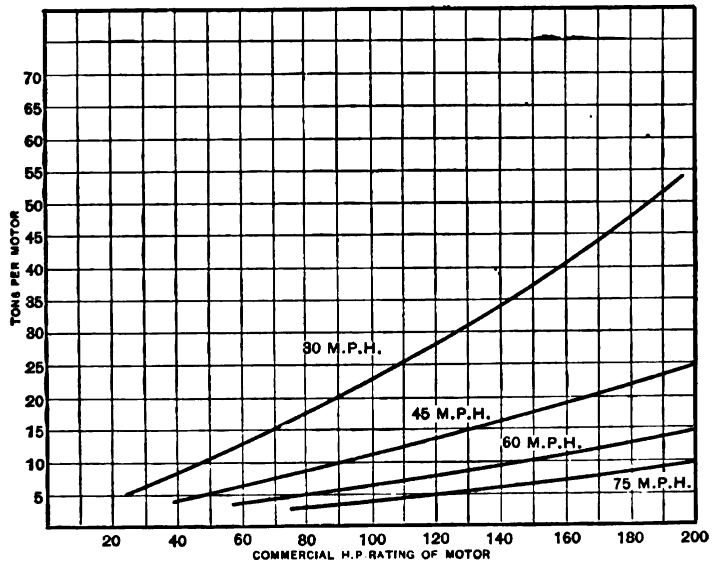


Fig. 8.—Motor Capacity 60° C. Rise. C. Friction Curve.

Assuming that the road will be double track with 80 lb. track rails and 100 lb. third rail, the distance apart of the substations will be approximately 13 miles with a maximum drop of 170 volts when two cars are passing midway between substations, one of which is accelerating. This drop is permissible as it is momentary only. Each substation must be able to accelerate one car and supply another at full speed, or must give 850 amperes momentary output and a sustained output of 500 amperes. The substation will therefore be called upon to deliver momentarily 510 k.w. and should contain not less than one 300 k.w. rotary converter and preferably two, one being a reserve. This size of converter is based upon the assumption that cars run always as single units and not in trains, and that converters can stand a momentary overload of 100 per cent. With half-hour service cars will be spaced 20 miles apart, so that there will be required a generator capacity of two cars every 20 miles (double track) or 340 k.w. assuming 15 per cent. loss in rotary converter substations and transmission line. The generating station capacity per mile of track will therefore be 17 k.w., and the substation 46 k.w. with reserve, and 23 k.w. with no reserve. Taking the cost of generating station in round numbers at $100 per k.w. and substation at $35, the cost of a 40-ton car complete with four 110 h.p. motors, controllers, etc., at $9,000, we arrive at the following approximate cost for installing:

APPROXIMATE FIRST COST PER MILE, SINGLE CAR TRAIN

Generating station	$1,700
Substations with reserve	1,610
Equipment (plus 20% reserve)	1,120
Total	$4,430

The above total of $4,430 thus represents the approximate first cost of the various items noted when operating a single 40-ton car every half hour at 40 m.p.h. schedule speed and stopping 15 seconds once in four miles. Following through the same process with two 40-ton cars operating on one hour headway at 40 m.p.h. schedule with the same track and third rail construction, we arrive at the following conclusions:

Watt-hours per ton mile	63
Train energy at train (80 tons)	202 k.w.
Distance apart substations	9.1 miles.
Size of substation	two 400 k.w. units.

Each train consisting of two 40-ton cars will consume 224 k.w. at the substation, or 264 at the generating station, allowing the same percentage of loss as above. These trains making the same schedule speed at double the headway will be spaced 40 miles apart and the generating capacity will therefore be 528 k.w. every 40 miles, or 13.2 k.w. per mile. The substations consisting of two 400 k.w. units (with reserve) every 9.1 miles will have capacity per mile of 88.0 k.w. Expense for cars will be the same as before and the following approximate costs obtain

APPROXIMATE FIRST COST PER MILE. TWO-CAR TRAIN.

Generating station	$1320
Substations	3080
Equipments	1120
Total	$5520

The first cost of the two-car train system will be $5,520 as against $4,430 with single-car train. The energy consumed for the two methods of operation is 17 k.w. per mile of track with single car as against 13.2 k.w. per mile with two-car train. Thus, while the two-car train at one hour headway will cost 24½ per cent. more to install (for the items mentioned only) it will consume but 77.6 per cent. of the energy required to operate a single car individually.

The difference in power required, is 3.8 k.w. per mile of track. Assuming 12 hours per day operation at the above headway, the total k.w. hours per day will be 45.5, which at $.007 per k.w. hour would be $116.50 per year, or 10 per cent. on $1.165. It would therefore pay to invest the $1,090 per mile of track difference in cost between one car and two car operation, as found above, provided the same receipts could be secured with one hour headway as with 30-minute headway. The relation of traffic receipts and frequency of travel is a question which can only be determined experimentally, and while the desirability of the two-car service seems evident from the data at hand in the above case, it might result in a falling off of receipts, to such an extent as to more than make up the saving in operating expenses. There is an additional saving in train-crew expenses which was not entered into above, and which would amount to something more than half as much as the cost of power. With two-car operation, it is possible to reduce the motor capacity per car from four 110 h.p. motors to four motors of approximately 95 h.p., thus reducing the cost of the equipment item. Owing to the fact, however, that it might be desired to operate a single car during certain parts of the day, which would result in overheating the smaller motor equipment, it would be more conservative to consider the same size of equipment whether one-car or two-car train were operated. With more than two cars in a train, advantage could be taken of the smaller equipment required, but it is probable that in two-car work this advantage of the smaller motor possible for two cars would only result in the cooler operation of these motors when operated in two-car trains and would show up therefore in the repair account rather than as a first cost. The substations with two-car trains being placed somewhat closer together would have a labor account per mile of track in excess of that for single car operation. This may be balanced against the saving which would result from smaller crew expenses of the two-car train.

These examples serve to illustrate the very broad application of the foregoing curves. Although it has been necessary to assume a number of constants, acceleration, braking, coasting, etc., these constants are those pertaining to average operation and can vary considerably without making a serious difference in the results. The curves given are not therefore absolutely correct, but are sufficiently so for approximation purposes. For the slower speed work where stops are more frequent and where acceleration is a more important factor, it will be necessary to have more complete curves to determine the proper rate of acceleration to use, especially if the problem is one calling for very high schedule speeds in relation to the number of stops.

As previously stated, it is not necessary that friction curves A, B and C should represent the actual friction in pounds per ton of train two-car and single-car work. Having the motor capacity and energy values for three different friction rates at a given maximum speed, it is possible to interpolate and secure the proper motor capacity and energy value for the friction value corresponding to the case in hand. The importance of the wind-friction as affecting electrical operation at a very high speed in service which has followed along the lines of very small light trains of one or more cars, will probably lead to the construction of special cars reducing wind-friction to a minimum when the higher maximum speeds are put into commercial operation. No conclusive data is at hand upon the effect of different shaped car-ends on single or two-car operation. When such data becomes available and special cars are constructed. their operation can be predicted from the foregoing curves by interpolation for the new friction values thus obtained.

The compilation of the above curves entailed a large amount of careful work, and the writer is very much indebted to F. I. Gould for his very valuable assistance.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 30, 1903.

STORAGE-BATTERY INDUSTRIAL LOCOMOTIVES.

BY F. L. SESSIONS.

General treatment of subject of equipment of industrial locomotives with storage-batteries. Batteries employed as (1) the only source of energy supply; (2) as the main source of energy supply; (3) as an auxiliary source of energy supply. Arrangements for charging. Relation of energy storage and discharge capacities to locomotive duty. Data, tables and examples of their use.

Among the various agents employed in handling material about industrial plants, the electric storage-battery is taking a position of prominence. The limits of its field of usefulness for street and interurban railway service have been pretty thoroughly determined by costly experiment and the calculations of competent engineers. It is probable that conclusions which have been reached in such service have until recently been considered applicable to other services in which the storage-battery might be used. The demands of recent industrial activity have, however, caused engineers to give much attention to the handling of material, and carefully to determine the energy and power requirements of the problems involved. This has led to the development of a great many devices and machines for reducing the time and expense of handling material. The study of such problems of different magnitudes has led the writer to the conclusion that the energy and power demands of many of them are well within the range of electric storage-battery service, and the results already achieved with storage-battery industrial locomotives have fully proved the conclusions reached.

Among the prominent advantages of these locomotives are convenience, safety and economy. No other form of industrial locomotive can compete with the storage-battery in the matter of convenience. It can be operated at night when other sources of power are cut off; it can be operated by an inexperienced person; it is ready for operation the instant it is required; it can be used as an energy supply for running motors or furnishing light whenever the usual power supply is cut off; it can be run over temporary tracks on wooden rails in special or emergency cases.

The storage-battery locomotive also excels in safety. Very few establishments are so arranged that either the overhead trolley or third-rail conductor would not be a source of inconvenience or danger at some if not all parts of the system of tracks necessary for the most convenient handling of material. Frequently where it is permissible to employ either a trolley or third-rail conductor over parts of the system, it is found prohibitive in other parts where a locomotive would be of most value. This is particularly the case in shops where overhead cranes and belting are used, and in buildings wherein inflammable materials are handled or stored.

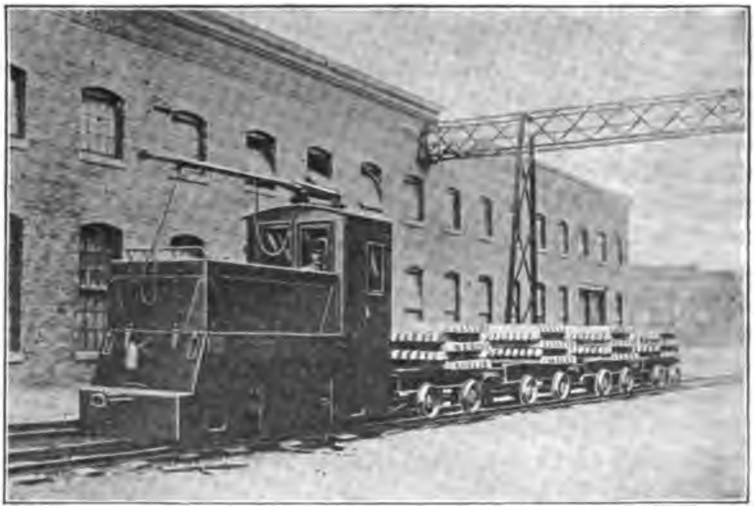


Fig. 1.

In the matter of economy it is probable that the storage-battery locomotive equals any other. Its average efficiency is as high as that of any other, and although on high discharge rates the battery efficiency may be low, the fact that when the locomotive is idle no energy is being used compensates for the low efficiency during high discharge periods.

While the storage-battery requires care and attention and may be rendered unfit for service through improper treatment or neglect, it is nevertheless true that any person of ordinary intelligence can readily learn to care for and operate it successfully and to cure its ordinary ills. Reduced to simple terms the requirements for the successful maintenance of an electric storage-battery are that the attendant perform a number of mechanical operations each day or at stated times, and take readings from certain instruments which are easier to learn to read than it is to learn to tell time by the ordinary clock. If these readings differ from prescribed figures, the attendant must perform other simple mechanical operations which produce results in the battery about which the attendant need have no knowledge, but which restore the cells to their normal condition.

In this paper all statements and data which may depend upon the type of storage-battery, refer only to the usual lead-lead type, as that to date is the only successful electric storage-battery available for use upon industrial locomotives.

In considering the equipment of a storage-battery locomotive, the subject will be divided under the following heads: batteries, motors, control and protection.

BATTERIES.

In the equipment of a locomotive with a storage-battery, the conditions of service and work to be performed determine the capacity of the battery to be used. In some instances a heavy locomotive may best be provided with a small storage-battery, while in others it may be best to equip a light locomotive with the largest storage-battery possible. In general, a storage-battery upon a locomotive is employed to fill one of the three following offices:

1. It may be employed as the only source of energy supply.
2. It may be employed as the main source of energy supply.
3. It may be employed as the auxiliary source of energy supply.

Batteries used for any one of these three purposes may be arranged to be charged.

(*a*) While on the locomotive at a charging station.

(*b*) While on the locomotive operating on trolley or third rail

(*c*) While removed from the locomotive.

A locomotive may be equipped with a storage-battery as its only source of energy supply, when the duty is such that it can be performed on a single charge, or when there are times in which the battery may be charged on the locomotive at a charging station, or when two or more sets of batteries are provided and a fully-charged battery is placed on the locomotive whenever the one in use becomes discharged.

A storage-battery may be employed as the main source of energy supply, and a trolley or third-rail conductor used on portions of the track where excessive grades, sharp curves, heavy loads or other conditions render the storage-battery inadequate.

As an auxiliary source of energy supply a storage-battery may be used on locomotives running partly within buildings or portions of yards where safety, convenience or other reasons make a trolley or third-rail conductor undesirable, but where on other parts of the track the trolley or third-rail conductors are permissible and desirable.

It will readily be seen that an accurate knowledge of the conditions of service and of the work to be performed is necessary before determining what batterye-quipment to provide. In determining the capacity of a storage-battery for any installation, the principal requirements are to provide a sufficient energy-storage capacity, and one which can develop sufficient power for the maximum demands. To move a given load a given distance will require the expenditure of the same amount of energy whether the work is done in one minute or ten minutes; but to move the load over the distance in one minute will require ten times the power that is required to do the work in ten minutes. For either case a storage-battery could have the same energy-storage capacity, but in one case the battery should be capable of delivering its energy ten times as fast as is necessary in the other case. The amount of energy which a fully-charged storage-battery can deliver depends upon the rate at which the battery is discharged. If discharged at a low rate, its storage capacity is less than when discharged at a high rate. If the rate of discharge is too high, the battery deteriorates rapidly. In general, the one-hour rate is the highest at which a battery should be regularly discharged,

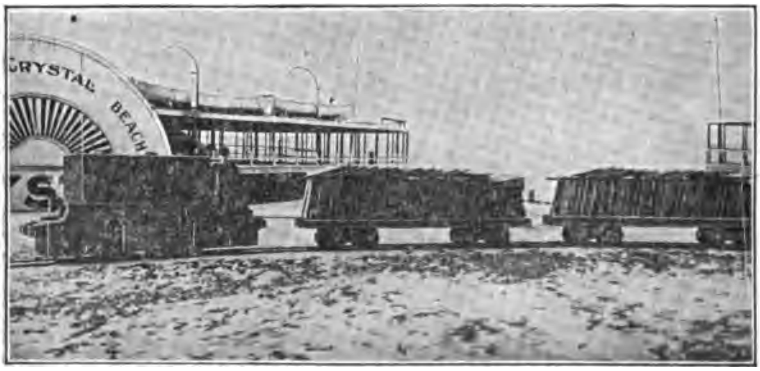


FIG. 2.

although for short periods a higher rate may occasionally be used. In selecting a storage-battery for a locomotive, it is therefore important that the maximum power required does not exceed the one hour discharge rate, except momentarily as in starting loads; and that the energy-storage capacity is great enough to enable the locomotive to perform the duty required of it.

To facilitate calculations in the choice of a battery, a number of tables have been prepared, based upon units which make their use available for a wide range of problems and battery capacities.

Table I. gives the kilowatt-hours and draw-bar pull required to move one ton one hundred feet under different friction loads and on various grades at any speed. By multiplying the kilowatt-hours of this table by sixty, we obtain the actual power in kilowatts required to move one ton one hundred feet per minute.

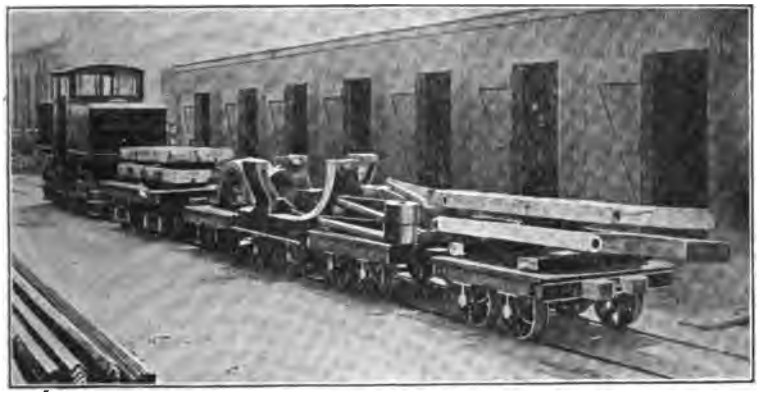


FIG. 3.

With this table, we are, therefore, able to determine both the energy-storage capacity and the kilowatts discharge rate necessary for any given duty.

The solution of the following problem will illustrate some of the uses of this table. A locomotive is required to haul 50 tons, including its own weight, up a 2 per cent. grade against a frictional resistance of 30 lbs. per ton a distance of 2,000 feet at a speed of 400 feet per minute. It is required to know: (1) The energy and (2) the power necessary.

The table gives .00264 k.w. hours to haul one ton up a 2 per cent. grade when the frictional resistance is 30 lbs. per ton; to haul 50 tons 2,000 feet will, therefore, require .00264 × 50 × 20 which equals 2.64 k.w.-hours of energy.

To obtain the power in kilowatts necessary to move one ton

TABLE I.

HAULAGE DATA

Kilowatt-hours and drawbar pull required to move one ton 100 feet under different friction loads and on various grades at any speed.

Grade.	Frictional resistance in pounds per ton on level track.							
	50	40	35	30	25	20	15	10
Level.	.001885 50	.001515 40	.001323 35	.001135 30	000943 25	.000758 20	.000568 15	.000379 10
½%	.00226 60	.001885 50	.001696 45	.001515 40	.001323 35	.001135 30	.000943 25	.00758 20
1%	.00264 70	.00226 60	.00207 55	.001885 50	.001696 45	.001515 40	.001323 35	.001135 30
1½%	.00302 80	.00264 70	.00245 65	.00226 60	.00207 55	.001885 50	.001696 45	.001515 40
2%	.0034 90	.00302 80	.00282 75	.00264 70	.00245 65	.00226 60	.00207 55	.001885 50
2½%	.00377 100	.0034 90	.00323 85	.00302 80	.00282 75	.00264 70	.00245 65	.00226 60
3%	.00415 110	.00377 100	.00358 95	.0034 90	.00323 85	.00302 80	.00282 75	.00264 70
3½%	.00452 120	.00415 110	.00396 105	.00377 100	.00358 95	.0034 90	.00323 85	.00302 80
4%	.0049 130	.00452 120	.00434 115	.00415 110	.00396 105	.00377 100	.00358 95	.0034 90
4½%	.00528 140	.0049 130	.00472 125	.00452 120	.00434 115	.00415 110	.00396 105	.00377 100
5%	.00566 150	.00528 140	.00509 135	.0049 130	.00472 125	.00452 120	.00434 115	.00415 110
5½%	.00604 160	.00366 150	.00547 145	.00528 140	.00509 135	.0049 130	.00472 125	.00452 120
6%	.0064 170	.00604 160	.00585 155	.00566 150	.00547 145	.00528 140	.00509 135	.0049 130

Multiply the constant by 60 to obtain kilowatts for one ton 100 feet per minute.

Kilowatt-hours to move any load any distance.

$$\text{K w.-hrs.} = \frac{\text{Constant x Tons x Hundreds of feet}}{\text{Locomotive Efficiency.}}$$

Kilowatts to move any load at any speed,

$$\text{K.w.} = \frac{\text{Constant x 60 x Tons x Hundreds of feet per minute}}{\text{Locomotive Efficiency}}$$

one hundred feet a minute up a 2 per cent. grade with a frictional resistance of 30 lbs. per ton, the constant .00264 must be multiplied by 60 which gives .1584 k.w., and to haul 50 tons 400 feet per minute against the same resisting forces will require .1584 ×50×4 = 31.68 k.w.

The above calculations assume a locomotive efficiency of 100 per cent., which is impossible. If this efficiency is 70 per cent. then the energy required is 2.64/.7 = 3.78 k.w.-hours, and the power is 31.68/.7 = 45.25 k.w.

TABLE II.

STORAGE BATTERIES.

Total Kilowatt-hours available and Kilowatts discharge rates for batteries of different 8-hour ratings.

Nominal or 8-Hr. Rating.	Kilowatt-Hours.								
	5	10	15	20	30	40	60	80	100
5 Hrs.	4.38	8.75	13.12	17.5	26.25	35.	52.5	70	87.5
4 "	4.05	8.1	12.15	16.2	24.3	32.4	48.6	64.8	81
3 "	3.75	7.5	11.25	15	22.5	30	45	60	75
2 "	3.25	6.5	9.75	13	19.5	26	39	52	65
1 "	2.75	5.5	8.25	11	16.5	22	33	44	55
	Kilowatts.								
Nominal or 8-Hr. Rate.	.63	1.25	1.88	2.5	3.76	5	7.5	10	12.5
5 Hrs.	.88	1.75	2.63	3.82	5.25	7	10.5	14	17.5
4 "	1.01	2.03	3.04	4.05	6.08	8.1	12.15	16.2	20.3
3 "	1.25	2.5	3.75	5	7.5	10	15	20	25
2 "	1.63	3.25	4.88	6.5	9.75	13	18.5	26	32.5
1 "	2.75	5.5	8.25	11	16.5	22	33	44	55

A battery capable of discharging 45.25 k.w. on a one-hour discharge rate has a storage capacity of 82.3 k.w.-hours on an 8-hour discharge rate, as determined from the data given in Table II. Such a battery would be capable of operating under such a load continuously for one hour on one charge, as its storage capacity on a one-hour discharge rate is 45.25 k.w.-hours.

Table II. gives the total kilowatt-hours available and the kilowatts discharge rates of batteries of different nominal, 8-hour ratings. The corresponding quantities for a battery of any other capacity may be obtained by multiplying those for a 100-k.w.-hour battery by the relative capacity of the battery desired.

Table III. gives the total tons load that can be hauled by a 100-k.w.-hour storage-battery on various grades and with different frictional resistances at 100 feet per minute when the locomotive efficiency is 100 per cent. From this table may be computed the total ton-loads that any battery can haul at any speed. For example, let it be required to determine what load a 40-k.w.-hour battery can haul on a 2½ per cent. grade at a speed of 150 feet per minute when the frictional resistance is 30 lbs. per ton. In Table III. under 30 lbs. frictional resistance and 2½ per cent. grade is given 304 tons as the total load that can be hauled by a 100-k.w.-hour battery at 100 feet per minute. A 40-k.w. battery can, therefore, haul 304×40/100×100/150 = 81.2 tons, under the conditions assumed in the problem. If the locomotive efficiency is 70 per cent., it will be able to haul 81.2×.70 = 56.84 tons, including its own weight and that of the battery.

Table IV. gives the kilowatts for hauling 100 tons 100 feet per minute on various grades and with different frictional resistances. From this table may be computed the kilowatts for hauling any load at any speed. For example, let it be required to determine the capacity of a battery for hauling a total of 50 tons at 250 feet per minute on a 1 per cent. grade when the frictional resistance is 25 lbs. per ton. In Table IV. under 25 lbs. frictional resistance and 1 per cent. grade is given 10.2 k.w. for hauling 100 tons 100 feet per minute. To haul 50 tons at 200 feet per minute will, therefore, require 10.2×50/100×250/100 = 12.75 k.w. If the locomotive efficiency is 70 per cent., a storage-battery for such a duty should have a discharge capacity of 12.75/.7 = 18.21 k.w.

Table II. may be used to determine the nominal k.w.-hour rating of a battery having a discharge capacity of 18.21 k.w. In this table a 100-k.w.-hour battery is seen to be capable of discharging 55 k.w. for one hour. The k.w.-hour rating of a battery capable of discharging 18.21 k.w. for one hour will be proportional to that of the 100-k.w.-hour battery, or the battery required will have a nominal storage capacity of 18.21/55×100 = 33.1 k.w.-hours.

The foregoing problems are given as illustrations of the ways in which these data tables can be used in connection with storage-battery locomotive haulage. They will be found useful, also, in determining the motor capacity for locomotives, and

TABLE III.

STORAGE-BATTERY HAULAGE

Total loads in Tons that can be hauled by a 100 Kilowatt-hour Storage-Battery 100 feet per minute when the Locomotive Efficiency is 100%.

Grade.	Discharge Rate	Friction Loads in Lbs. per Ton.							
		50	40	35	30	25	20	15	10
Level	1 Hr.	488	605	690	808	973	1210	1615	2420
	2 "	288	358	410	478	575	718	975	1430
	3 "	222	276	315	368	444	553	735	1104
	4 "	179	223	255	297	358	446	593	890
	5 "	155	193	222	258	310	386	514	770
	8 "	111	138	158	184	222	276	368	554
½%	1 Hr.	405	488	540	605	690	808	973	1210
	2 "	240	288	320	358	410	478	575	718
	3 "	185	222	246	276	315	368	444	553
	4 "	149	179	199	223	255	297	358	446
	5 "	129	155	173	193	222	258	310	386
	8 "	93	111	124	138	158	184	222	276
1%	1 Hr.	348	405	443	488	540	605	690	808
	2 "	206	240	263	288	320	358	410	478
	3 "	159	185	202	222	246	276	315	368
	4 "	128	149	163	179	199	223	255	297
	5 "	111	129	141	155	173	193	222	258
	8 "	79	93	101	111	124	138	158	184
1½%	1 Hr.	304	348	375	405	443	488	540	605
	2 "	180	206	221	240	262	288	320	358
	3 "	138	159	171	185	202	222	246	276
	4 "	112	128	138	149	163	179	199	223
	5 "	97	111	119	129	141	155	173	193
	8 "	69	79	85	93	101	111	124	138
2%	1 Hr.	270	204	325	348	375	405	443	448
	2 "	160	180	192	206	221	240	262	288
	3 "	123	38	148	159	171	185	202	222
	4 "	100	112	120	128	138	149	163	179
	5 "	86	97	104	111	119	129	141	155
	8 "	62	69	74	79	85	93	101	111
2½%	1 Hr.	243	270	284	304	325	348	375	405
	2 "	143	160	168	180	192	206	221	240
	3 "	111	123	144	138	148	159	171	185
	4 "	90	100	104	112	120	128	138	149
	5 "	77	86	94	97	104	111	119	129
	8 "	56	62	65	69	74	79	85	93
3%	1 Hr.	220	243	257	270	284	304	325	348
	2 "	131	143	152	160	168	180	192	206
	3 "	101	111	117	123	144	138	148	150
	4 "	81	90	94	100	104	112	120	128
	5 "	71	77	82	86	94	97	104	111
	8 "	51	56	58	62	65	69	74	79
3½%	1 Hr.	203	220	231	243	257	270	284	304
	2 "	120	131	137	143	152	160	168	180
	3 "	92	101	106	111	117	123	144	138
	4 "	75	81	85	90	94	100	104	112
	5 "	65	71	74	77	82	86	94	97
	8 "	47	51	53	56	58	62	65	69
4%	1 Hr.	188	203	212	220	231	243	257	270
	2 "	111	120	125	131	137	143	152	160
	3 "	85	92	96	101	106	111	117	123
	4 "	69	75	78	81	85	90	94	100
	5 "	60	65	68	71	74	77	82	86
	8 "	43	47	48	51	53	56	58	62

generator capacity necessary for operating locomotives upon trolleys or third-rail systems. On account of the efficiency of locomotives varying with many conditions, the data tables have been based upon that efficiency being 100 per cent.

Tables I., III. and IV. show clearly the advantage of reducing the frictional resistance of the train as much as possible. In most industrial plants the tracks can be made practically level and as friction forms a greater part of the load which the locomotive has to haul, the battery capacity necessary depends upon the frictional resistance ot the train. Every means which tends to reduce this item of energy consumption adds rapidly to the radius of action of the locomotive and to the efficiency of the haulage system.

TABLE IV.

HAULAGE DATA.

Kilowatts required to move 100 Tons 100 feet per minute under different friction loads and on various grades when the Locomotive Efficiency is 100%.

Grade.	Frictional resistance in pounds per ton on level track.							
	50	40	35	30	25	20	15	10
Level	11.3	9.1	7.9	6.8	5.7	4.6	3.4	2.3
½%	13.6	11.3	10.2	9.1	7.9	6.8	5.7	4.6
1%	15.9	13.6	12.5	11.3	10.2	9.1	7.9	6.8
1½%	18.1	15.9	14.7	13.6	12.5	11.3	10.2	9.1
2%	20.4	18.1	17.0	15.9	14.7	13.6	12.5	11.3
2½%	22.6	20.4	19.4	18.1	17	15.9	14.7	13.6
3%	24.9	22.6	21.5	20.4	19.4	18.1	17	15.9
3½%	27.2	24.9	23.8	22.6	21.5	20.4	19.4	18.1
4%	29.4	27.2	26	24.9	23.8	22.6	21.5	20.4
4½%	31.8	29.4	28.3	27.2	26	24.9	23.8	22.6
5%	34	31.8	30.5	29.4	28.3	27.2	26	24.9
5½%	36.3	34	32.9	31.8	30.5	29.4	28.3	27.2
6%	38.5	36.3	35.2	34	32.9	31.8	30.5	29.4

Table V gives the kilowatt-hours required to charge a battery to move one ton 100 feet, when discharging at various rates and hauling trains against various friction loads and grades, the energy efficiency of battery on eight-hour discharge rate being 75% and the locomotive efficiency being 100%.

. TABLE V.

Kilowatt-hours required to charge a battery to move one ton 100 feet, when discharging at various rates and hauling trains against various friction loads and grades, the energy efficiency of battery on 8-hour discharge rate being 75% and the locomotive efficiency being 100%.

Grade	Discharge Rate.	Friction Load in Lbs. per ton.							
		50	40	35	30	25	20	15	10
Level,	1 Hr.	.004570	.003670	.003210	.002755	.002285	.001840	.001290	.000919
	2 "	.003865	.003110	.002715	.002325	.001935	.001556	.001092	.000777
	3 "	.003350	.002695	.002355	.002020	.001680	.001350	.000947	.000674
	4 "	.003100	.002495	.002180	.001870	.001552	.001250	.000877	.000624
	5 "	.002875	.002310	.002018	.001730	.001437	001157	.000868	.000577
	8 "	.002512	.002020	.001765	.001513	.001256	.001011	.000758	.000505
½%	1 Hr	.005475	.004570	.004115	.003670	.003210	.002755	.002285	.001840
	2 "	.004630	.003865	.003480	.003110	.002715	.002325	.001935	.001556
	3 "	.004020	.003350	.003020	.002695	.002355	.002020	.001680	.001350
	4 "	.003720	.003100	.002790	.002495	.002180	.001870	.001552	.001250
	5 "	.003440	.002875	.002585	.002310	.002018	.001730	.001437	.001157
	8 "	.003010	.002512	.002261	.002020	.001765	.001513	.001256	.001011
1%	1 Hr.	.006400	.005475	.005020	.004570	.004115	.003670	.003210	.002755
	2 "	.005415	.004630	.004250	.003865	.003480	.003110	.002715	.002325
	3 "	.004695	.004020	.003680	.003350	.003020	.002695	.002355	.002020
	4 "	.004350	.003720	.003410	.003100	.002790	.002495	.002180	.001870
	5 "	.004020	.003440	.003155	.002875	.002585	.002310	.002018	.001730
	8 "	.003520	.003010	.002760	.002512	.002261	.002020	.001765	.001513
1½%	1 Hr	.007325	.006400	.005940	.005475	.005020	.004570	.004115	.003670
	2 "	.006200	.005415	.005020	.004630	.004250	.003865	.003480	.003110
	3 "	.005370	.004695	.004360	.004020	.003680	.003350	.003020	.002695
	4 "	.004970	.004350	.004035	.003720	.003410	.003100	.002790	.002495
	5 "	.004600	.004020	.003730	.003440	.003155	.002875	.002585	.002310
	8 "	.004025	.003520	.003265	.003010	.002760	.002512	.002261	.002020
2%	1 Hr.	.008250	.007325	.006835	.006400	.005940	.005475	005020	.004570
	2 "	.006975	.006200	.005780	.005415	.005020	.004630	.004250	.003865
	3 "	.005060	.005370	.005010	.004695	.004360	.004020	.003680	.003350
	4 "	.005600	.004970	.004640	.004350	.004035	.003720	.003410	.003100
	5 "	.005180	.004600	.004300	.004020	.003730	.003440	.003155	.002875
	8 "	.00454	.004025	.003760	.003520	.003265	.003010	.002760	.002512
2½%	1 Hr	.009145	.008250	.007840	.007325	.006835	.006400	.005940	.005475
	2 "	.007740	.006975	.006635	.006200	.005780	.005415	.005020	.004630
	3 "	.006710	.006050	.005750	.005370	.005010	.004695	.004360	.004020
	4 "	.006210	.005600	.005330	.004970	.004640	.004350	.004035	.003720
	5 "	.005730	.005180	.004925	.004600	.004300	.004020	.003720	.003440
	8 "	.005030	.004540	.004315	.004025	.003760	.003520	.003265	.003010
3%	1 Hr.	.010075	.009145	.008700	.008250	.007840	.007325	.006835	.006400
	2 "	.008520	.007740	.007350	.006975	.006635	.006200	.005780	.005415
	3 "	.007380	.006710	.006375	.006050	.005750	.005370	.005010	.004695
	4 "	.006840	.006210	.005910	.005600	.005330	.004970	.004640	.004350
	5 "	.006330	.005750	.005455	.005180	.004925	.004600	.004300	.004020
	8 "	.005540	.005030	.004775	.004540	.004315	.004025	.003760	.003520
3½%	1 Hr.	.010950	.010025	.009610	.009145	.008700	.008250	.007840	.007325
	2 "	.009275	.008520	.008130	.007740	.007350	.006975	.006635	.006200
	2 "	.008040	.007380	.007050	.006710	.006375	.006050	.005750	.005370
	4 "	.007440	.006840	.006520	.006210	.005910	.005600	.005330	.004970
	5 "	.006890	.006330	.006040	.005750	.005455	.005180	.004925	.004600
	8 "	.006030	.005540	.005280	.005030	.004775	.004540	.004315	.004025
4%	1 Hr.	.011870	.010950	.010540	.010075	.009610	.009145	.008700	.008250
	2 "	.010050	.009275	.008920	.008520	.008130	.007740	.007350	006975
	3 "	.008710	.008040	.007730	.007380	.007050	006710	.006375	.006050
	4 "	.008065	.007440	.007160	.006840	.006520	.006210	.005910	.005600
	5 "	.007465	.006890	.006620	.006330	.006040	.005750	.005455	.005180
	8 "	.006530	.006030	.005795	.005540	.005280	.005030	.004775	004540

From this table the cost of haulage by storage-battery locomotives under the given conditions can be approximately determined. As the energy efficiency and storage capacity vary with different conditions of electrolyte and with the cycle of voltage through which the battery is charged and discharged this table cannot be considered accurate for all cases. A complete review of each individual case is necessary for determining the exact energy input of a battery for a given duty.

Motors.

The motors for storage-battery locomotives should be series wound and properly proportioned and geared for the duty of the locomotive. The essential requirements of these motors have to do chiefly with control and will be discussed further under that subject.

Control.

Industrial locomotives may be divided into three classes; viz., those used for hauling other cars; those in which the load is carried upon the locomotive, and those used for both carrying and hauling. In the case of a locomotive used only for hauling other cars, the maximum tractive effort which it can exert depends upon the material and condition of the wheels and rails, but with either of the other two classes mentioned the maximum tractive effort depends upon the load carried by the locomotive.

The best method of control for an electric storage-battery locomotive, like the equipment, depends also upon the duty and kind of service the locomotive has to render. In some instances it is necessary to equip the locomotive with every appliance for charging the batteries as well as for controlling the speed, while in others the charging apparatus may be installed at a charging station and the locomotive equipped with means for speed control only.

Speed control may be effected by grouping the battery cells; by use of a variable resistance, or by a combination of cell grouping and variable resistance. When two or more motors are used, variation in speed may be had by series and parallel connections of the motors.

The character of storage-batteries renders it unwise to charge or discharge them more rapidly than at a given safe rate, or beyond a given cell terminal voltage. This makes it necessary to provide circuit-breakers or other protective devices to prevent these limits being exceeded. In some instances the motors and battery have been designed so that when the battery is delivering its maximum safe current, the drive-wheels will be almost on the point of slipping; and any greater current causes the wheels to slip, thus relieving the motors and battery. Such an equipment, if at all desirable, can be safely used upon locomotives employed for hauling only, and where the battery and motors are correctly proportioned and grouped for such results. Locomotives equipped with batteries as an auxiliary source of energy supply can seldom carry sufficient battery capacity for slipping the drivers, and those locomotives used for carrying have such a variable maximum tractive effort that protection by wheel-slippage is out of the question. For a general equipment, then, it seems best to employ an overload and voltage-limit circuit-breaker for discharging the battery and an overload and underload circuit-breaker for charging it.

For uniform life all of the battery cells should be worked alike. To accomplish this, the number of cells in series must be continually halved to make the various groupings. By using a maximum of four groups, three speeds may be had without altering the motor connections, and by connecting the motors in series and parallel a fourth speed is possible. With two motors in parallel and three battery groupings, the relative speeds are: ¼, ½ and 1, corresponding respectively to battery grouping of four groups in parallel, two groups in parallel and two in series, and all four groups in series. By throwing the motors in series and four groups of cells in parallel, a relative speed of ⅛ is obtained.

A very satisfactory arrangement is one in which the motors are connected permanently in parallel, the battery is divided into four groups and a variable resistance is used in grading each of the three speeds available by battery grouping. Without a variable resistance for grading the starting effect, the gears, motors and battery all receive severe strains when the terminal voltage is suddenly doubled.

In determining the best equipment to use, two classes of service are frequently presented. In one class the locomotive is called upon to exert a large effort at a slow speed or a small effort at a higher speed. In the other class, the effort of the locomotive is practically the same at all speeds. In the first class the total current capacity of the two motors in parallel and the cells in four groups should be equal. With the motors and batteries thus connected, the maximum effort would be obtained and at each successive grouping of the cells a lesser effort at a proportionately higher speed would be had. In the second class the batteries connected all in series should have a current capacity equal to that of the two motors in parallel. With this arrangement the maximum effort would be obtained at the maximum speed and with other groupings of the cells the same effort at lesser speed would be possible. For the same maximum effort the motors and battery in the first class may be only one fourth the capacity of those in the second class.

The illustrations, Figs. 1, 2 and 3, are views of different storage-battery locomotives at work. The locomotive shown in Fig. 1 is arranged so that the battery may be charged and the locomotive operated at the same time by current collected by the trolley. Over portions of the track a trolley wire is not permissible and upon such portions the battery is used for operating the locomotive. Ordinarily, the battery is charged only while operating on the trolley line. The batteries are connected permanently in series and speed-control is effected by variable resistance as in ordinary street railway service. A separate charging resistance and switch is provided.

The locomotive shown in Fig. 2 is equipped with a 20-k.w. storage-battery as its only source of energy supply. It is so arranged that the same resistance and controller that are employed for speed-control are also used for charging the battery. Charging plugs are placed at convenient points and the locomotive service is so arranged that after ten hours' operation the battery still has 65 per cent. of a full charge available. The batteries are connected permanently in series. The locomotive and battery together weigh 7½ tons.

The illustration in Fig. 3 is of a 12-ton, double-truck locomotive equipped with a 25-k.w.-hour battery. Each truck has both its axles driven by a single motor through flexible connecting links. The batteries are connected in four groups, and speed-control is effected by battery grouping only. A separate charging switch and resistance are employed, and charging is done at stations provided for the purpose.

From results obtained through both calculation and experience it appears that the electric storage-battery when properly designed for its duties can be employed with greater advantages and economy than any other known form of energy storage supply for industrial locomotives. It is probable that somewhat special elements will be required as it seems impossible to secure the necessary life and strength for the plates without making them especially heavy. This is not ordinarily a disadvantage with industrial locomotives as the weight is necessary for traction. As in all other problems in which energy and power have to be considered, the results obtained with storage-batteries will be exactly those for which provision has been made.

DISCUSSION.

MR. EDGAR H. BERRY:—I concur fully in the opinion expressed by the author as to the special suitability of the storage-battery for use on industrial locomotives. Its convenience, safety and ease of maintenance have been so clearly explained that comment on these points seems unnecessary. I wish, however, to take exception to the statement on page 968, which implies a very material reduction in the battery efficiency when discharging at a high rate. As a matter of fact, a storage-battery maintains its efficiency very well over a considerable range of loads. I will have occasion to refer to this further in connection with one of the tables presented in the paper.

Durability and depreciation have not been touched upon at all. Unfortunately, or perhaps I should take the point of view of the user and say fortunately, I am not able to say how long it takes to wear one of these locomotives out. The oldest one I know of has been in constant operation for over four years, and the original battery-plates are still doing their full duty. In his book on storage-batteries, Mr. E. J. Wade figures the depreciation on stationary cells by assuming a life of three to six years for positive plates, and of five to ten years for negative plates. Judging from the case I have in mind, a good battery of the type usually employed for stationary work will not suffer any reduction in its useful life when used on an industrial locomotive. Even when the plates reach a point at which it will be economical to replace them, the balance of the locomotive should still be perfectly serviceable for a further indefinite period.

An arrangement is mentioned on page 980 for charging from a trolley or third rail while the locomotive is in use. If this has proved successful it would be very interesting if we could hear just how it was done. Unless the feeders were large enough to keep the voltage at the locomotive practically constant, it would seem as if the charging current would fluctuate between undesirably wide limits. The current does not vary directly as the impressed voltage, but approximately as the difference between this voltage and the voltage of the battery. I have taken readings during a charge that have shown a change of over 13 per cent. in the current for a change of 1 per cent. in the voltage. The battery in question consisted of 44 cells, the normal charging rate being 20 amperes. At a certain state of the charge 105.5 volts were needed to maintain the normal rate, but an increase of four volts, making a total of 109.5 gave a current of 30 amperes. A jump of four volts on a 110-volt trolley circuit would be nothing unusual, but a charging current of one and one-half times the normal would be highly undesirable near the end of the charge, when it would cause wasteful gassing, and probably injurious heating.

To ensure the selection of a suitable battery it would seem necessary to add one more condition to those given at the top of page 971. This additional requirement to be worded "and that the permissible charging rate be high enough to permit of charging in the time available for that purpose." This is highly important, for if the battery is worked at the one-hour rate, which is usually about four times the normal charging rate, the charging time must be four times as long as the discharging time, or four hours. If this is not available, a larger battery, or two sets of battery, must be employed. In many cases the larger battery would give a cheaper, simpler and more desirable solution. Of course if the service is very heavy an extra removable battery may become absolutely essential.

Passing now to the tables, I find a slight discrepancy between Table I. and the example given to illustrate its use. If the figures in the table are intended to apply to the total load, including the locomotive, the latter is charged with the same friction loss as the cars, and then in addition it is afterwards charged with its own efficiency loss. By adding one more column to the table, giving the kilowatt-hours needed to move one ton 100 feet up the various grades with a friction of zero pounds per ton, it would be possible to determine separately the work of lifting the locomotive, and of hauling the cars. The sum of these two, divided by the efficiency of the locomotive would give the true result. Under the efficiency I understand the ratio between the energy effective at the wheels, and the energy developed at the battery terminals.

Assuming the coefficient of traction to be one fifth, the error in the table as it now stands runs from two and one-half per cent. at a friction loss of 10 pounds per ton, to twelve and one-half per cent. at 50 pounds per ton. It is, however, all on the safe side.

Of course I do not know what make of battery was used as a basis for Table II., but the discharge and capacity at the higher rates seem too large. For instance, the one-hour rate in amperes is usually taken at four times the eight-hour rate, making the output in ampere-hours for a one-hour discharge, one half of that for an eight-hour discharge. But the extra $I^2 R$ loss at the higher rate cuts down the voltage, and consequently the watt-hours. Their value for a one-hour rate should therefore be less than 50 per cent. of the value for an eight-hour rate. The table gives 55 per cent., making the kilowatt-hours for the one-hour rate over 10 per cent. higher than the figures I have been in the habit of using.

In connection with Tables III. and IV., mention is made on page 974 of the importance of cutting down the friction loss of the cars as much as possible To emphasize this I may point out that poor bearings in the cars may easily halve the load which a locomotive can haul on a level track. Or, putting it in another way, they may necessitate the use of two locomotives instead of one.

Table V. has puzzled me somewhat, but in talking it over with Mr. Sessions this morning I find that he bases it on an assumption which seems to me to be very unfair to the locomotive. If we accept this table we must admit that at a high discharge rate a battery is completely discharged at the end of the number of hours corresponding to that rate. This of course is not a fact, for when a battery has reached the point at which it can no longer maintain the high rate of discharge, it can still discharge for a further period at a lower rate; the sum of the watt-hours at the different rates, being equal to the watt-hours used in charging, less the unavoidable loss due to a transformation of energy. If the discharge is stopped when the high rate can no longer be maintained, it is only necessary to put back as many watt-hours as were taken out, plus the transformation loss. Just what this loss is at different discharge rates I am not prepared to say, and I do not know that any definite data in regard to this point have ever been published. Perhaps our committee on engineering data can unearth some information about it. But in any event I feel safe in saying that the efficiency at a one-hour rate is nearer to 70 per cent. than to 41 per cent., which is the figure used in the table.

Up to this point all the calculations have been made in kilowatts and in kilowatt-hours, the exact current and voltage being immaterial as long as their product had a suitable value. But now in selecting a specific motor and suitable gears the battery voltage becomes important and this in turn should preferably be such that it will be possible to charge directly from some available source of supply. Furthermore, it is highly desirable to use standard commercial sizes of batteries and motors, and these must be so chosen that the combination fits the original assumptions as closely as possible. Exact agreement could of course only occur by chance, and I have found it most desirable to select a gear-ratio which will fit the ampere-torque-curve of the motor, and to allow the speed at a given load to differ slightly from the original assumed value, according to the degree of accuracy with which the battery and motor actually employed approximate to their calculated sizes.

The use of a resistance for controlling the speed does not seem justifiable on a storage-battery locomotive. Aside from the actual waste of power in the resistance, extra time is needed for charging, and the battery capacity is virtually reduced. Even when only a single motor is employed, two groups of cells and a split series-field give four speeds, which seem to be ample to meet all requirements. The split-field is arranged so that the two halves can be thrown in series or in parallel with each other. With two motors the possible combinations are further increased as the motors themselves can be connected in series and parallel arrangements.

If the resistance is used for starting only, the power wasted in it may of course be negligible, but with an ignorant or thoughtless operator the loss may assume larger proportions. The term "fool-proof" was unknown before electricity came into general use, but the public having once discovered that apparatus *can* be so built, immediately uses it on the assumption that it *is* so built, and the locomotive designer has no choice but to fall in line.

Another safeguard against abuse is pointed out at the bottom of page 978. The locomotive can be so proportioned that the wheels will slip before either the motor or the battery is seriously overloaded. This arrangement has proved highly satisfactory in actual use, and it seems to be the best and simplest method of protection that can be devised. It provides a safety-valve that cannot get out of adjustment, and that cannot be tampered with in any way short of piling dead weight on the locomotive.

A question may be raised as to the desirability of a voltage-limit circuit-breaker. This, I take it, is to open the circuit when the battery voltage falls below the allowable limit, thus calling attention to the necessity for an immediate recharge. Suppose, now, that this opens when the locomotive is some distance from the charging station. To get back, the locomotive must either be hauled, or else the circuit-breaker must be held in. The average operator I think will choose the latter method. But running a locomotive while holding in a circuit-breaker is not convenient, and the obvious remedy is to tie in the arm. This leads easily to the next step of having the arm tied in continually, when the locomotive will be in the dangerous situation of being supposedly protected by a device which actually is inoperative. On the other hand it is a simple matter to make the operator understand that he must recharge as soon as the voltmeter needle falls to a certain point.

An underload and overload circuit-breaker in the charging circuit seems to be very desirable, but it must not be forgotten that the underload release may fail to protect if the voltage of the charging line fluctuates. A very slight increase in the line voltage may continuously maintain the current above the point at which the underload release operates. If, however, the conditions are such that the line voltage is constant, the underload release affords an excellent protection.

In speaking of a locomotive called upon for a large effort at a low speed, and for a smaller effort at a higher speed, the paper suggests connecting the cells in four parallel groups for the first case, and connecting them all in series for the second case. I would like to inquire what safeguard is provided to prevent the operator from throwing all the cells in series, even when the higher effort is required. This would take four times the permissible current from the battery, but would not overload the motor, and therefore would neither slip the wheels, nor open the circuit-breaker.

The employment of extra heavy battery-plates, which is mentioned at the close of the paper as a possible necessity has many disadvantages, and in the light of past experience it hardly seems called for. The additional expense of special plates would add materially to the cost of the locomotive, and the advantages to be derived are open to serious question. I would not recommend the use of a light-vehicle battery on a locomotive, but the type ordinarily used for stationary work seems to possess ample strength. If more weight is necessary to give adhesion, pig iron will be just as serviceable as battery plates costing 30 to 40 cents per pound. Or if dead weight is to be eliminated at all costs, a larger battery might be employed, giving more reserve capacity, and requiring less time for a normal charge.

While weight is of course necessary to give adhesion, it is well to bear in mind that even a heavy locomotive may be deficient in hauling power unless all, or practically all the weight is on the drivers. All other weight in the locomotive means a corresponding reduction in the load that can be hauled. Assume for example a ten ton locomotive, in which all the wheels are drivers, and which can just haul a load of ten tons up a certain hill without slipping the wheels. If only half the weight of this locomotive were on the drivers, it could just climb the hill alone, without load.

In conclusion, I wish to express my appreciation of the paper before us. Industrial locomotives are new, comparatively speaking, and I believe that the present paper is the first one on this subject to be presented before this INSTITUTE. If such a pioneer paper possesses any interest at all it is bound to start a discussion in which differences of opinion will be in evidence. I have endeavored to show my interest in the paper by finding as much fault as possible, and I trust that some of the other members will show their interest in the discussion in the same way.

MR. SESSIONS:—In reply to the question of protection by circuit-breaker when the batteries are connected in either series or parallel, I would say that the circuit-breaker, if especially adapted for the work, will open so as to protect the batteries when the locomotive develops a smaller effort at higher speed. The circuit-breaker for this purpose may appear complicated at first glance, but it differs from the ordinary overload circuit-breaker only in necessitating several wires running to it instead of the ordinary two. The tripping-magnet is wound in as many sections as there are groups of cells and each group of cells is connected in series with one of these sections. The sections of the tripping-magnet coil, therefore, are in series or parallel in the same way that the cells are, and for the same current drawn from one group of cells the ampere-turns upon the tripping-magnet are always the same.

I should like to take up further some of the points touched on by Mr. Berry. I admit that the example illustrating Table I. is not accurately solved and that it errs exactly as Mr. Berry states, but an error of 2½ per cent. is hardly worth calculating for the general run of storage-battery problems, and a slight allowance in the locomotive efficiency will compensate the inaccuracy. As yet the refinements of the art are not such as to demand calculations within that limit. Table I., itself, is absolutely correct and will be found very convenient.

With regard to the charging rate for storage-batteries, and also with regard to Table II.. in which the one-hour discharge capacity is given as 55 per cent. of that for eight hours, it is a fact that both of these features depend radically upon the method of forming the plates and I must maintain that the figure is accurate for batteries suitable for industrial locomotives. Certain formations of plates will not stand the high discharge that others will.

As to the efficiency of the storage-battery locomotive, I wish to take a stand for conservatism in this respect—perhaps there is a slight ambiguity in assuming that a battery is entirely discharged at any one rate, at a high rate especially, but such an assumption is necessary where the locomotive duty is unknown. In Table V. I have assumed that the battery is fully charged when starting to discharge, and that it is discharged to the safe limit without any time given for recuperation. I have stated in reference to Table V ,

> " As the energy efficiency and storage capacity vary with different conditions of electrolyte and with the cycle of voltage through which the battery is charged and discharged, this table cannot be considered accurate for all cases."

In each case where the battery of a locomotive is to be charged and discharged in repeated cycles, it will be necessary to review an entire day's work in order to get a complete and accurate lot of data for determining the energy required for that locomotive.

The use of resistance for starting and controlling storage-battery locomotives has proved to be a very satisfactory arrangement, and the energy losses in the resistance are not considerable enough ordinarily to be an objection, when consideration is given to the cost of maintenance and the severe strains put upon various members when the motor terminal-voltage is instantly doubled.

As to charging the battery while the line is supplying current for operating the locomotive, I will say that this has been proved highly successful and economical in several instances. It is probable that a battery does not have so long a life when it is thus used, as there is a temptation always to charge at a high rate, but, as our compressed air friends would say, " efficiency is not alone the ratio of the energy output to the energy input." It depends upon the results in the work for which the battery is designed.

Mr. Elmer A. Sperry:—I would like to call attention to the rapidly growing demand for locomotives of this nature, the nature described in this paper. I believe that they are going to fill a want that has been attempted on the part of our compressed air friends. Two or three years ago I was called upon to make some comparative tests of locomotives of this nature and those operated by compressed air, and, in conformity with the last remark of Mr. Sessions, it would seem that our compressed air friends are not strong in the matter of efficiency. That is, they do not rely very materially on this factor. The results of calculations that were made at the time to which I refer might be interesting to you, as pointing not only to the matter of efficiency but also as comparing the weights necessary to be carried in the two instances to do the same work. We usually think the storage-battery, being made of lead, is an extremely heavy and cumbersome affair to carry the energy that it is enabled to develop and supply. Now, as a matter of fact, the compressed air, when re-heated—not taking into consideration the weight of the re-heating apparatus—but simply considering the weight of the compressed air drum, and in this instance, as I remember it, the pressure of the air was something like 3700 pounds to the square inch—we found that the amount of energy capable of being supplied per ton of compressed air, together with its tank, as compared with the ton of storage-battery all told, was in the neighborhood of 23½ per cent. only, in the case of compressed air, less than one quarter. And, as over against this consideration, we have another. That is, the compressed air factor is running down as it is exhausted. For instance, when the compressed air is half exhausted, the pressure is half gone; when three quarters exhausted, the pressure is only one quarter of the initial pressure; whereas, in the case of the storage-battery, the curve is almost ideal. The battery, when we have exhausted it one half is still almost at the same pressure as when we started; when exhausted three quarters it is still nearly the same, the curve, as you remember, being almost horizontal. I think, as I said before, that there is a gradually widening field for the storage-battery car.

[Communicated after Adjournment by Edgar H. Berry.]

The writer has taken up the question of battery efficiencies at different discharge rates with a well-known company which has had a wide experience in the manufacture and maintenance of storage-batteries, and whose records contain a considerable fund of information in regard to the actual performance of its cells.

This company states that "assuming the efficiency of 75 per cent. for the 8-hour charge and discharge rates to be correct, the amount of energy required to recharge after a discharge at the 5, 3, or 1-hour rate, would be exactly proportionate to the amount taken out—so long as the charging was done at the normal rate."

On this basis all the figures in Table V., excepting those applying to the 8-hour rate, should be eliminated, and the figures for the 8-hour rate should be taken as applying to the 8-hour, 1-hour and all intermediate rates.

The writer does not for a moment wish to advocate the deliberate selection of a high discharge rate, but he does insist that the objections to such a course do not arise from an increase in the watt-hours per unit of work, necessary for charging. The penalties imposed by a high discharge rate are similar to those incurred when any piece of apparatus is worked very near its ultimate limit of endurance. A high discharge rate means a low factor of safety for carrying an overload, a very low reserve storage capacity, and a considerable increase in the risk of injury to the plates when handled by unskilled persons. These are the considerations that must be set against the increased cost of the larger battery in determining the proper size to give the highest ultimate commercial efficiency.

[COMMUNICATED AFTER ADJOURNMENT BY F. L. SESSIONS.]

In commenting upon Mr. Berry's supplementary note, I would say that I desire to give the storage-battery credit for whatever efficiency it may have. Table V. is correct as it stands for the conditions assumed. Mr. Berry seems to overlook those conditions, and to distort the data given by assuming other conditions for the sake of giving the storage-battery a better face. It is difficult in compiling data to choose that which will be convenient for every case, and that which is not applicable should, of course, not be used.

The statement of a battery manufacturer, which Mr. Berry quotes, is probably correct for the conditions assumed. In this connection I would say that I should be more than delighted to learn the name of any battery manufacturer who will guarantee either efficiency or capacity, or assume any responsibility for his products after they leave his factory.

[DISCUSSION ON PAPER BY F. W. CARTER.]

MR. C. O. MAILLOUX:—This paper is not so abstruse as it looks. The equations appear somewhat formidable and imposing but in reality they present no great difficulty. The method is assumed to be an analytical method. but there are some statements, on the first page, in reference to the " graphical " or the point-to-point method of construction, which make it desirable that I should begin the discussion by considering the point-to-point method. At the last annual meeting I read a paper entitled, " Some Notes on the Plotting of Speed-Time Curves," in which I described a graphical point-to-point method. I had intended to present, this year, at this meeting, another paper, giving an analytical method, which was hinted at in the discussion at Great Barrington (see A.I.E.E. TRANSACTIONS, Vol. XIX., p. 1018), but lack of time prevented me from doing so.

I want to say something in support of the point-to-point method presented in my paper. It is a method which involves no assumptions except that the rate of retardation is assumed constant in braking. We still have to make that assumption because we have no very definite knowledge as to the nature of the braking curve; but with that exception the method is independent of any assumptions. All the data necessary for use with this method can be obtained from motor tests and from experiments; and once the fundamental curves, which I showed on the " chart of coefficients," (Fig. 9 of my paper) have been plotted, it is possible to plot the speed-time curves for any set of conditions whatever, with any desired degree of accuracy, and with little difficulty.

Mr. Carter's method, as presented, cannot presume to be more than a method of approximation, and consequently it does not altogether supplant or replace the methods described in my paper.

Singularly enough, the author, himself comes rather close, in some details, to my method; for his Fig. 9, on the last page of the paper, is substantially identical with Fig. 9 of my paper: The solid-line curve in Fig. 9, is one which gives gross tractive efforts as a function of the speed. The author uses the ordinates for tractive efforts per motor, in pounds. The abscissæ indicate speeds. In my paper, I also use abscissæ for speeds, and I use the same ordinate *values*, but they are plotted according to a different *scale*. I call them acceleration-coefficients (see curve M, Fig. 9, in A.I.E.E. TRANSACTIONS, Vol. XIX., p. 926; curves M. N. R. in Fig. 9*a*, are reproduced from Fig 9 of my paper) Now, the acceleration-coefficient is as is easily shown, nothing more than the tractive effort multiplied by a reduction factor, which we know to be 91.1. This factor (which we may here call F), includes the coefficients necessary to change weights from pounds into tons, to convert speeds from feet per second into miles per hour, and to take into consideration the gravity value or measure of acceleration; thus.

$$F = \frac{5280 \times 2000}{3600 \times 32.2} = 91.1$$

Consequently, if, without changing the curve, we change the scale in the ratio of 91.1 to 1, in either of the two curves, they become identical in mathematical character. They both have the same meaning; that is to say, the solid-line curve in Fig. 9 of this paper has precisely the same significance as curve M in Fig. 9 of my paper (see Fig. 9*a*). They both express the force which is available, per motor, for producing acceleration. What is still more remarkable is that the solid-line curve at the bottom of Fig. 9 of this paper, is identical with the curve R in Fig. 9 of my paper. It is the curve of train resistance expressed in terms of equivalent acceleration. The dotted-line curve which is the curve of net acceleration factors is also exactly the same as the curve N in Fig. 9 in my paper. (See Fig. 9*a*). Now, all that is necessary by the point-to-point method is a curve of that kind (N) and some means for readily determining the reciprocal values. This means is found in what is called, in my paper, the "chart of reciprocals." (Fig. 10 of my paper) which contains several reciprocal curves, by means of which we can get the relation between any speed-value and the corresponding time-value. Taking (from the curve N) one of the equivalent acceleration values corresponding to a given speed, we transfer it to the curves that will give its reciprocal; that reciprocal, for a certain increment of speed, will be the corresponding time-increment, when measured by a suitable time-scale.

This time-scale depends on the speed increment (Δv) for which the time increment (Δt) is to be determined. The same reciprocal curve could be made to serve for all speed increments, by suitably changing its scale. It is simpler, in practice, to use a special reciprocal curve for each different speed increment employed in determining the time values. The chart of reciprocals (Fig. 10 of my paper), contains a total of nine such reciprocal curves, which are found sufficient for all speed-increments between .01 and 10 m.p.h.

A method was recently suggested to me for doing this by Mr. L. A. Freudenberger, instructor in physics under Dr. Franklin, at Lehigh University. I had occasion during the past winter, by the kind invitation of Dr. Franklin and Professor Esty, to deliver some lectures on electric train movement at Lehigh University, and Mr. Freudenberger, who attended these lectures, indicated to me his modification of my method, which is of interest in this connection because it is a kind of connecting link between the point-to-point method and analytical methods such as outlined in Mr. Carter's paper.

In my paper, starting from the acceleration-coefficient ($k = \frac{dv}{dt}$), we can easily deduce the fact that the elemental time value ($d\,t$) is equivalent to the reciprocal $\left(\frac{1}{k}\right)$ of that acceleration coefficient, multiplied by the elemental speed ($d\,v$), or:

$$d\,v \times \frac{1}{k} = d\,t$$

(as given in Appendix C of my paper; see TRANSACTIONS, Vol. XIX., p. 986, equations *d* and *e*). Now, Mr. Freudenberger plots, on the same diagram with the curve *N* (see Fig. 9*a*), the reciprocals $\left(\frac{1}{k}\right)$ of the equivalent acceleration values, according to the equation just mentioned; and he gets a curve of reciprocals, *A* (which is shown in Fig. 9*a*). This curve would have its first portion exactly parallel to the axis of *x* until it reaches the point *b*, if the train resistance were constant at all speeds; but, in reality, it will rise slightly as shown in the diagram (Fig. 9*a*). From the point *b*, it rapidly changes to an upward course, reaching infinity at the speed-point corresponding to $\frac{d\,v}{d\,t} = 0$, which in the case represented in Fig. 9*a* would be 65.8 m.p.h. Now. knowing that the total time is, of course, equal to the integral

$$\int d\,t = t = \int \frac{d\,v}{k}$$

taken between suitable limits, he integrates the reciprocal curve *A*, and gets a curve of time values (*C*), which he plots according to a suitable time-scale. If this time-scale is placed on the same axis of coördinates as the " *k* " values (in Fig. 9*a*), then the integral curve (*C*) of the reciprocal curve *A*, *would be the speed-time curve itself.*

In using this method, Mr. Freudenberger transposes the coördinates of the curve *N*. He plots this curve with speeds as ordinates and the coefficients (*k*) as abscissæ, as shown in Fig. 9*b* This brings the time values along the axis of abscissæ, and, consequently, leaves the speed-time curve in a more natural position than is the case in Fig. 9*a*.

The main objection to the method is that it necessitates too many reciprocal curves (*A*). Every time that there is a change in train resistance, or, rather, in the net tractive effort, owing either to a grade or to a curve, then, evidently, the curve of net acceleration values represented by the dotted line in Fig. 9, also (Curve *N* in Fig. 9*a*) changes.

As was pointed out in my paper (see Vol. XIX., p. 929), the effect is the same as if the axis of ordinates were moved upward or downward, according to the case.

It is, therefore, necessary, for each change in condition, to redraw the reciprocal curve *A*, and to obtain a new integral curve (*C*) from this new reciprocal curve. While one could draw a set of curves for a large number of conditions, yet, as we have here three quantities, namely, gradients, curves, train resistance any one of which may have an indefinite number of values within rather wide limits, and as the same process would be repeated for each change in the motors or in the train load, the result is that it would, in practice, take an indefinitely large number of curves to fit varying cases and conditions, and to give a satisfactory approximation. The method has, therefore, more theoretical interest than practical utility.

A practical difficulty in the use of this method would arise from the mathematical circumstance that the ordinates of the reciprocal curve *A* approach infinity at the speed values at which the acceleration coefficient (Curve *N*, Fig. 9*a*) approaches zero. It will be readily seen that this complicates the process of plotting this curve and of integrating its area. The practical effect is to increase the difficulty of determining the proper time values for the " flatter " portions of the speed-time curves. It was precisely to overcome this difficulty that several reciprocal curves

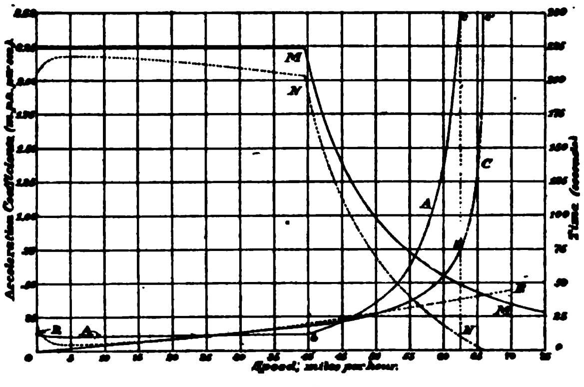


FIG. 9a.

are given in the Chart of Reciprocals (Fig. 10 of my paper). These different curves of reciprocals afford means whereby the " scale " can be changed according to the slope of the speed-time curve, or, in other words, according to the value of the acceleration-coefficient " *k*." It is obvious, for example, that the portion ($b' - c'$) of the speed-time curve *C*, which is drawn in dotted line in Figs. 9*a* and 9*b* could not be obtained by integrating the reciprocal curve *A*. according to Mr. Freudenberger's method, unless this curve itself were extended beyond the limits shown in the diagram. The flatter the speed-time curve (*C*) becomes, the greater will be the extension required in the reciprocal curve (*A*), whose limiting value is infinity, as already pointed out. The coördinates used for plotting the dotted portion ($b' - c'$) of the curve *C*, in Figs. 9*a* and 9*b*, were readily and quickly determined by using the charts of Coefficients and of Reciprocals, as described in my paper.

I now come to analytical methods such as outlined in the paper. At the last annual meeting, in the discussion of my paper, Mr. S. T. Dodd pointed out the importance of an analytical method, and spoke of his efforts in that direction. In my own discussion I stated that such a method was very desirable and that I hoped to find one. I said that it depended simply upon our finding an analytical or empirical relation between speed and current, tractive effort and current, and also between speed and tractive effort and train resistance. Now, Mr. Freudenberger has made one step in that direction to which I now wish to call attention. Mr. Freudenberger pointed out to me, some three weeks ago, on the occasion of one of my lectures, a fact of which I was not then aware, namely, that Prof. Carus-Wilson had worked out a theoretical or rational method, by means of which the curve (*N*)

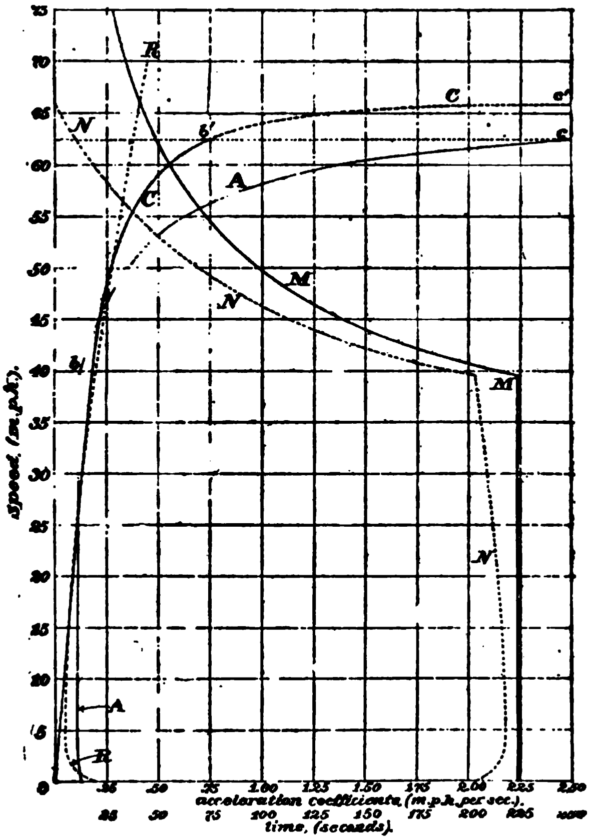


FIG. 9b.

of equivalent acceleration (or net tractive effort, as the author of the paper would perhaps call it), can be expressed analytically with a greater or less degree of approximation. Instead of determining the curve of equivalent accelerations (*N*), by reference to the data obtained from tests of a motor, Mr. Freudenberger proposed to determine it by a method due to Prof. Carus Wilson, and given in his book, "Electro-Dynamics—The Direct Current Motor." This is an interesting innovation.

The straight portion of the curve (*N*), it may be stated, corresponds to that portion of the speed-time curve during which the acceleration is controlled by the rheostat. This portion of the curve is generally supposed to be straight. In reality it is not straight; it has a slight downward bend (as shown in Fig. 9*a*), owing to the fact that the train resistance is not constant. The curve of gross tractive effort (*M*) is straight (on the assumption, of course, that the rheostatic control is such as to keep the current constant), but the net curve (*N*) has a slight droop.

As a matter of fact, with motor controllers having a limited number of steps, each step of the motor controller causes a variation of current and a slight "hump" in this portion of the curve. (See Vol. XIX., p. 966, last paragraph.)

The aim of an analytical method, as is properly stated in the paper, is to do away with plotting altogether, and still to be able to obtain accurate results—not merely approximations—under all conditions. I think the author would admit that the method as here given, is not susceptible of quite that accuracy. The method has apparently not been subjected to very extensive or severe practical tests. The illustrations given are really quite simple, not to say elementary, cases of speed-time curve plotting, and many of the real difficulties are to be overcome in introducing and using an analytical method are not considered, being apparently wholly unperceived by the author. The method, however, deserves commendation as being a valuable step in the direction in which we must look for the complete solution of the problem.

What is wanted is a method by means of which one can deal with not only simple and abstract, hypothetical, cases and conditions, but with specific, practical, cases and conditions of all kinds, especially those involving complications, such as curves occurring in the middle of a run, necessitating reductions of speed and repeated acceleration in the middle of the run—cases, for instance, such as shown in Fig. 13 of my paper (see Vol. XIX., p. 946). It is, perhaps, well to point out that for such cases—and others still more complicated—the method under discussion would be wholly inadequate, whereas the point-to-point method, or the "interpolation" method described in my paper is entirely adequate.

The analytical method, to sum it up in a few words, requires simply an equation that will enable us to connect the time-values with the speed-values. If we have that, the rest is a mere matter of mathematical manipulation.

Now, the general equation itself is a simple one to establish. I worked it out several years ago, and have been hoping to find a method of introducing the functional-coefficients, so as to be able to use it practically. We start from that same equation which we have already derived, which gives us t. If we express speeds (v) in miles per hour and weights in tons of 2000 lbs., and take $g = 32.2$, and so on, as before, we can easily reduce this to this well-known form:

$$t = 91.1 \int_{v'}^{v''} \frac{d\,v}{p}\quad .$$

where v = m.p.h.

p = net tractive effort in lbs. per ton of 2000 lbs.

If, however, we wish to express it in terms of the difference between the gross and the net tractive effort, the equation takes this form:

$$t = 91.1 \int_{v'}^{v''} \frac{d\,v}{P \pm G - f - C \pm R}$$

In the denominator we have the total (gross) tractive effort (P) plus or minus grade effect (G), (the sign depending upon whether the grade is "*up*" or "*down*"), minus train resistance effort (f), minus the curve resistance (C). We might add anothe rfactor (R), with plus or minus sign, which would indicate the rotative kinetic energy of the train. Now, the integral of that equation would give us the formula connecting t, with v, in any case. The general equation might be written thus:

$$d\,t = \frac{d\,v}{(f^{\kappa})\,v - (f\lambda)\,v \pm G \pm R - C}$$

The first term in the denominator, the "κ" function of the speed, is nothing more than the equation of the curve of gross tractive effort which is given in Fig. 9 of the present paper, and also of my paper (see Fig. 9*a*). The "λ" function of the speed is the equation of the curve of train resistance. The grade effect (G), the curve effect (C), the rotative and kinetic energy R, are easily and perfectly determinable under all conditions. As this equation shows, we need only two things to be able to predetermine speed-time curves. We need equations for the κ and λ "functions" of the speed, of form such that they can be "substituted" in the general equation. Now, Mr. Carter gets one of them by using a hyperbolic formula to connect speed and tractive effort. In other words, he finds that the speed-tractive effort curve is of hyperbolic type. Unfortunately, he has made certain assumptions by which he sacrifices precision to attain simplicity. Prof. Carus Wilson's method possibly furnishes a more satisfactory formula for the "κ" function. I myself strove to find an equation connecting the two variables together; but I looked a little further, for I wanted a method of precision, and not merely one of approximation. It is proper to point out here that it is not enough to have the speed-time curve. As shown in my paper, the speed-time curve is only a stepping-stone to the curves which are really of interest and utility—the subsidiary curves, such as the curves of electric current and electric power input and their integral curves, which tell us much that we want to know. Consequently, it is not enough to have a means of plotting speed-time curves. We want more than a means of readily plotting the subsidiary curves—we want a means of obviating the plotting of them, and of obtaining, nevertheless, the results which they would give us and which we now have to obtain by plotting them and laboriously integrating them by mechanical methods. Hence, it is necessary and desirable that we should find not only the curve which connects speed with current, but also the curve which connects tractive effort with the current and also with the speed. Looking at the speed-current and the tractive-effort current curves, one would at once recognize the first as belonging to the hyperbolic family and the other to the parabolic family. It is in that direction I have worked, but I have tried to do it by one type of equation that would fit all cases. Here are two equations of x^n functions: $y = b\,x^n \pm a$: $y = b\,(x \pm a)$. The remarkable mathematical peculiarity of that function is that when n has the negative sign. we have hyperbolas, and when n has the positive sign. we have parabolas. there being an endless number of each, corresponding to the endless series of n values between $+\propto$ and $-\propto$. The effect of a is merely to shift the axes of coördinates. In the first equation a serves to shift the axis of y; in the second, it serves to shift the axis of x. The sign is + or – according to the direction in which the axis is shifted. The effect of b (*i.e.*, of variation in b), is merely to change the scale of ordinates. When the scale is the same as for abscissæ, we have $b = 1$, and the equation becomes simplified in form. It can be shown, mathematically, that only one coefficient (b) and only one constant (a) need enter into that equation to enable us to express with a fair degree of accuracy any single branch curve of the hyperbolic and of the parabolic type.

All that is necessary, therefore, is to find out whether the sign of a is positive or negative for these cases, and to determine the most suitable values of b and a. I find that this can be done with relative facility. . I have tried it in the case of the speed-current and tractive-effort current curves of a *G E* 65 and of a *G E* 55 motor, and I find that the empirical curves, that is to say, the curves derived by an empirical equation of this " x^n " type, are so close to the original curves that unless the scale is very large, the two curves will coincide fairly well.

The empirical formula takes the form

$$y = b\,(x - a)^n$$

for the curve of tractive effort, and

$$y = b\,(x-a)^{-n} = \frac{b}{(x-a)^n}$$

for the curve of speeds, when x = current, in amperes (in both cases). With the ordinary scale on which these curves are plotted in the data sheets issued by the manufacturing companies, one would hardly see the difference between the " actual " and the " empirical " curves.

I want to point out that the effect of b, as it enters here, depends mainly upon the gearing ratio and the voltage. It simply has the effect of moving the curves (that is, their ordinates) up or down, in exactly the same way as is done by a change in voltage or in gear ratio. I have not yet fully determined the effect of a. It has apparently some relation to the amount of current required to produce the " friction torque," and possibly also to the resistance of the motor and other things like that.

The formula of Mr. Carter for the speed-current curve is quite as satisfactory as one of the x^n form, and may even have some advantages over it. His formula for the tractive effort curve, however, presumes or assumes a straight line relation, and, consequently, it is unsatisfactory for any method except one of approximation.

The train resistance itself (our " λ " function), after it has been determined by a rational formula (of form which need not be discussed now) can be expressed quite closely, for any given case, by an empirical equation of this (x^n) type.

Mr. Carter finds it desirable, in order to simplify his method, to assume that the train resistance is either constant, or else, may be treated as if it were sub-divided into graded steps. These assumptions are, of course, inadmissible in a method of precision.

If we are able to express the three principal variables, speed, torque, train resistance, by equations of the same type, we can easily find, by an equation of *similar* type, the other relations, such as, for instance, the relation between torque and speed, which is our " κ " function (Curve M). This function can be expressed by a formula of the form

$$y = \frac{b}{x^n}$$

The rest is nothing but a matter of relatively simple mathematical manipulation. It will then be possible to calculate the data for the speed-time curve, also the current and power input curves, and to obtain from them, by *analytical* integration, the distance-time curve, the energy input curve, and various other important subsidiary curves We will thus obtain the energy value corresponding to a given acceleration cycle, and to any sets of such cycles constituting a " service run." It is also evident that we can then introduce changes of grade, of curvature, train resistance, etc., and, in a word, take into account all the possible conditions and modifications. One can then play all the changes desired upon the " theme," and still have absolutely correct and determinate results, without any approximations. A complete analytical method will, when it has been developed, enable us to do all this. Mr. Carter deserves much credit for having prepared and presented this paper, which shows important progress in the right direction and contains many useful suggestions, in addition to being, even in its present form, useful for making preliminary. approximative calculations.

[COMMUNICATED AFTER ADJOURNMENT BY MR. C. O. MAILLOUX.]

The method of Mr. L. A. Freudenberger referred to in my discussion of Mr. Carter's paper, has since been made public by its author in two articles printed in the *Electrical World and Engineer*. The first article, entitled, " Plotting of Speed-Time Curve from the Acceleration-Speed Curve," and published in the issue of July 18th (Volume XLII., pp. 96–97). The general description of the method given in this article is substantially as given in my discussion. The second article, entitled, " Plotting of Speed-Time and Speed-Distance Curves from the Acceleration-Speed Curve," and published in the issue of August 9, 1903 (Volume XVII., pp. 219–221), is a continuation of the first communication. This second article contains some interesting extensions and developments of the method and gives a practical example illustrating the application and use of the method in plotting one of the same Run Curves which was used by me as an illustration in my paper (" Notes on the Plotting of Speed-Time Curves ").

The particular run selected by the author as a practical illustration of the use of his method is that described as " Service Run No. 7," illustrated in Fig. 12 of my paper, and described in Volume XIX., on pp. 1079–1088. The reader who is interested in doing so is thus enabled to make a comparison between the two methods, when both are applied to the same case.

The extensions of the method mentioned in Mr. Freudenberger's second article only partly remove the objections to the method, as stated in my discussion. The modified method requires the construction of two accessory curves—one giving the values v/a as a function of the speed, and the other the distance values as a function of the time.

The writer finds by experiment that the modified method does not shorten or simplify the process of plotting a given Run Curve, as compared with the " chart " method described in my paper, and it is, of course, much more laborious than the " Interpolation " method, also described in my paper. The method may, however, be of utility in some cases.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 30th, 1903.

INTERURBAN CAR TESTS.

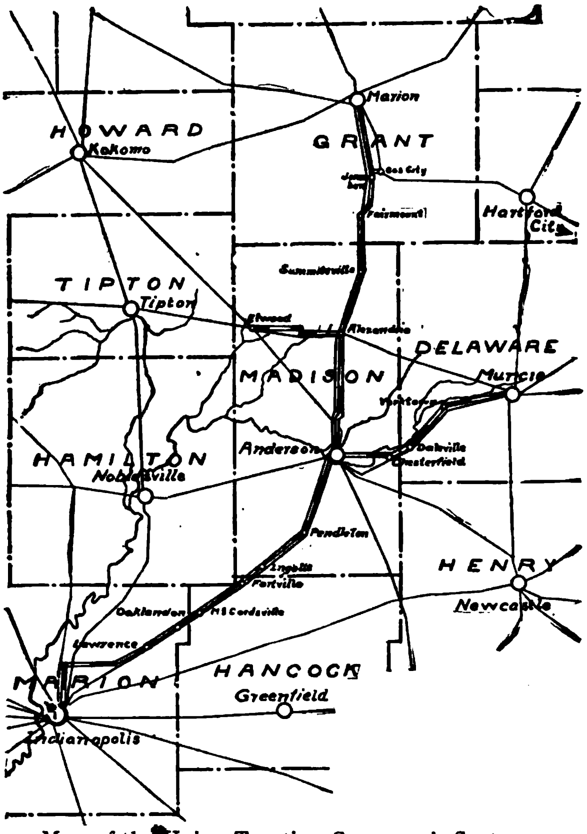
BY W. E. GOLDSBOROUGH AND P. E. FANSLER.

INTRODUCTORY STATEMENT.—The car tests which form the subject of this paper were made on the cars of the Union Traction Company of Indiana. It would not be fair to say that the success of the tests has been due to any one group of individuals, as a relatively large number of experimenters have generously contributed to the work. The great interest taken in interurban practice by George F. McCullough, President of the Company, made the test possible. A. S. Richie, Electrical Engineer, Charles A. Baldwin, Supt. of Transportation, and John Matson, Master Mechanic, put themselves to great inconvenience to render every assistance.

Charles. F. Scott, Clarence Renshaw and B. B. Abry, of the Westinghouse Company are largely responsible for the excellent outcome of the special tests. Mr. Renshaw took a leading part in this work and has contributed a valuable article on the special car tests to the *Street Railway Journal* of October 4, 1902. In connection with the work of calibrating instruments, preparing for the tests, making records and working up results, Messrs. Dostal, Zapp, Peticolas, Hoft, Hollingsworth, Dinsmore, Smith, Starkey and Weaver, senior students in electrical engineering at Purdue University worked hard and well. In the preparation of this paper the results obtained by the various experimenters have been drawn on indiscriminately.

INTRODUCTION.

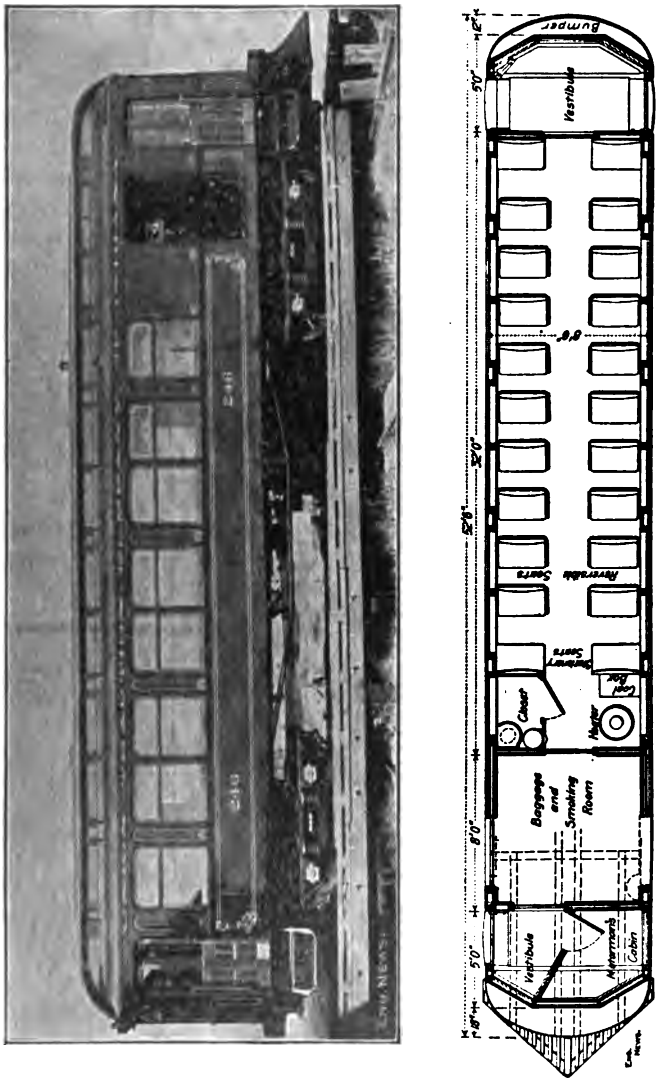
There are many factors in the problem of interurban electric transportation which have as yet received very inadequate attention. As in all new branches of engineering the first thing sought is successful operation. The economies follow in good time. Although we are but entering upon the era of interurban electric traction, properties of this nature have come into being so rapidly that by their very weight in numbers they have attained to great perfection in detail on account of the enormous concentration of engineering skill that has been brought to bear on them. This accounts for the fact that we are already aiming at the ultimate economies, and the report of which this paper is the subject is but one of many efforts in this direction.



Map of the Union Traction Company's System.

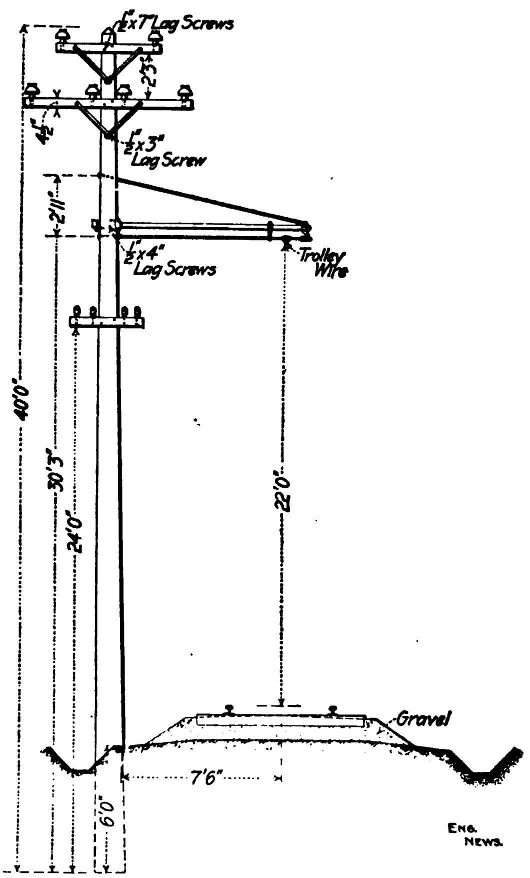
The Union Traction Company of Indiana operates a system extending over five counties and connecting the principal towns between the cities of Indianapolis, Anderson, Muncie and Marion. The system as it stands to-day is a fine example of electric railway engineering and is generally admitted to have been developed along very fine lines. At the time of the tests the company was operating more than 160 miles of track, 110 miles of which was interurban, the remainder local.

The tests were made on the interurban lines between Indianapolis and Muncie at various times during the springs of 1902 and 1903, although the greater portion of the data was recorded in connection with the general test of the system which occurred April 17, 18 and 19, 1902, and at the time of the special interurban car tests which occurred between March 20th and March 29th, 1902.



Interurban Car used by the Union Traction Company of Indiana.

The country between Indianapolis and Muncie has a general appearance of being level. It is, however, quite rolling in part and there are few good level stretches. The interurban road bed is accordingly subject to frequent variations in grade and contains numerous curves. The grades as a rule do not run above 2 per cent. There are a few that run as high as 3 per cent. but they are relatively short. The roadbed is well constructed, the track being made solid with good balasting. Seventy-pound rails are used



Standard Pole Line Construction of the Union Traction Co. of Indiana.

From Indianapolis the line passes on through Ingalls, and Lawrence to Anderson and from Anderson through Daleville to Muncie. In Table III. the intermediate points are given together with the distances between same.

The interurban trains are of two kinds, those known as local trains and those known as through or limited trains. The first stop at all towns and at frequent intermediate points or for flag stations; the rule being that the local trains will stop to pick up passengers at any point where a county road crosses the interurban track. The limited cars work on a through schedule between Indianapolis and Muncie, stopping only at Anderson.

The trains are controlled through a very well developed train dispatching system. All the motormen receive their instructions from and report to the train dispatcher at frequent telephone connection boxes along the track. To put himself in communication with the train dispatcher it is only necessary for the motorman to insert his telephone plug into the connections of the telephone box without leaving his car, as each car is equipped with a telephone set. The train schedule is carefully worked up and all cars are required to run exactly on time.

Power is delivered at 550 volts to the interurban trains on the Indianapolis-Muncie Division from substations located at Lawrence, Ingalls, Anderson, Daleville and Muncie. The main power station is located at Anderson, and supplies energy over a high-tension, three-phase transmission system to rotaries in the various substations.

The cars used on the Indianapolis-Muncie Division are all of the same type. They are 52 feet 6 inches over all and weigh 63,100 pounds. The motive power equipment of these cars consists of two number 50 C motors, which are mounted on the forward truck and are nominally rated at 150 h.p. each. The motors are geared with the ratio of 20 to 51 and are geared to 36 inch wheels. Records were obtained from 10 cars of this type and also from two other cars differently equipped. As the latter were only used in the special tests they have no bearing on the general tests made on April 17th, 18th and 19th.

GENERAL CAR TESTS.

In making preparations for the general tests, the first thing necessary was to secure sufficient ammeters and voltmeters, and recording wattmeters of the railway-car type. Finally the details were arranged, and at the time of the test each car was fitted with a Thompson recording car wattmeter and also with a Westinghouse ammeter and voltmeter. The instruments were placed on the left-hand wall of the motorman's vestibule and hence were very easily accessible for reading. The wattmeters were all calibrated in position on the cars by the following method: A voltmeter and ammeter previously standardized were used to calibrate the Westinghouse voltmeters all connected in parallel and the Westinghouse ammeters all connected in

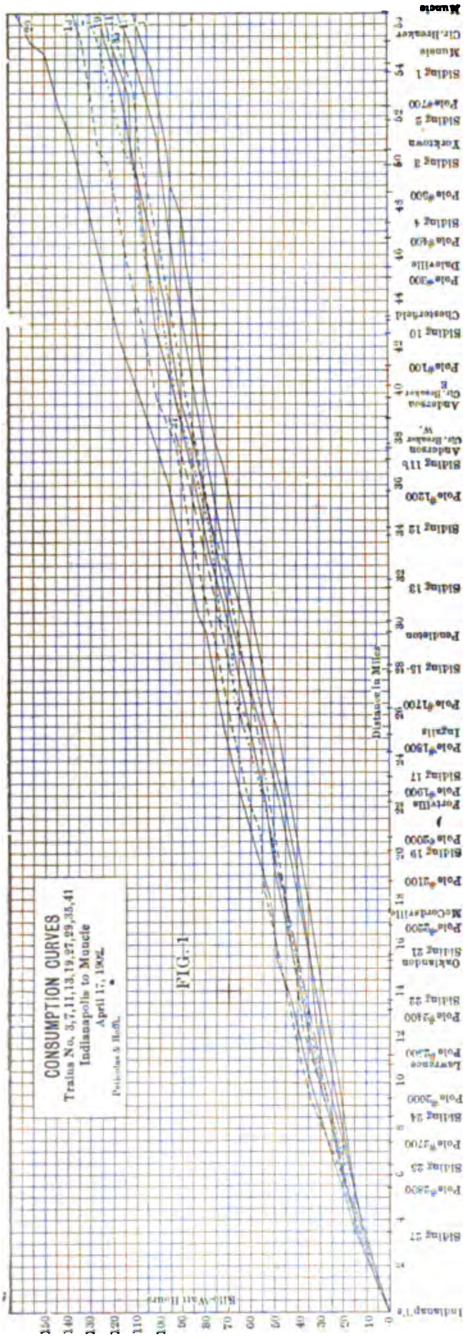

CONSUMPTION CURVES
Trains No. 3,7,11,13,19,27,29,35,41
Indianapolis to Muncie
April 17, 1902
Distance in Miles
Kilo-Watt Hours
Indianapolis
Muncie

FIG. 1

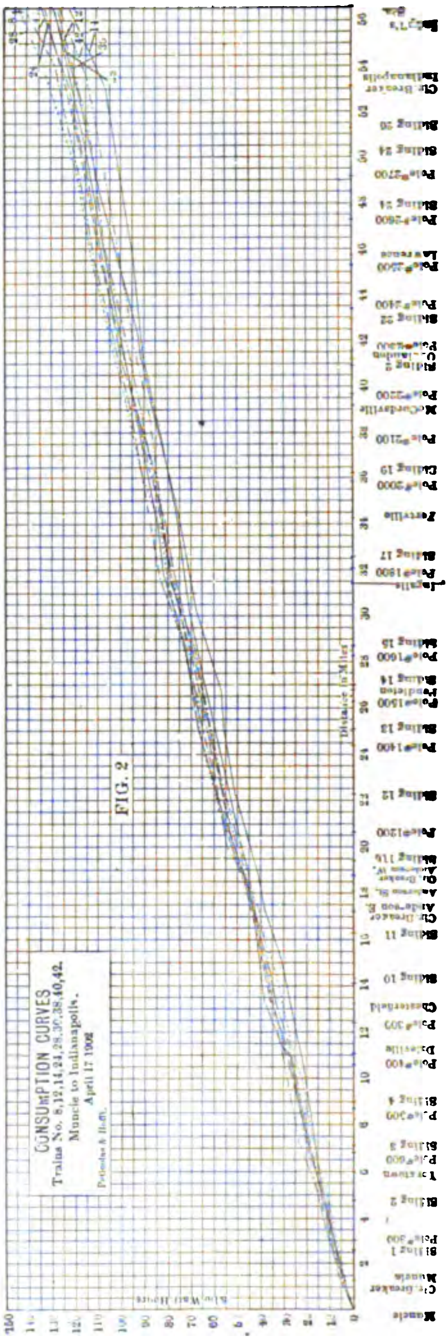

CONSUMPTION CURVES
Trains No. 8,12,14,24,28,30,38,40,42.
Muncie to Indianapolis.
April 17 1902
Distance in Miles
Kilo-Watt Hours
Muncie
Indianapolis

FIG. 2

series. The ammeters and voltmeters were then placed on the cars and used in calibrating the car wattmeters.

Between Muncie and Indianapolis the different cars were taken in turn by two observers and readings of the voltmeter and ammeter were recorded as rapidly as possible between stops. Simultaneously with these readings, readings were taken of the time and of the rate of rotation of the wattmeter disk. From the data thus accumulated the wattmeter constants were checked.

The objects of the general tests on the interurban and limited cars were:

First.—To determine in detail the k.w. hour consumption of individual cars, both local and limited, between stated points, en route from Muncie to Indianapolis and vice versa.

Secondly.—To average these results and to determine as well the maximum and minimum k.w. hour consumption over the route.

Thirdly.—To ascertain in so far as possible the general effect of starts and the personality of the motormen as factors in car consumption economy.

In accumulating data for these purposes, an observer was placed on each of the interurban cars operating between Indianapolis and Muncie throughout the three days of the general test. These observers were instructed to take wattmeter readings at all stops, at all circuit-breakers and to read both ammeter and voltmeter at intervals of every fifteen minutes.

The results of their work on April 17th is shown in part in the curves of Fig. 1, 2, 3 and 4; and in Table I. is given the record of all of the trains operated east and west on this day. The curves of Fig. 1 are interesting from the fact that they show the progressive increase in the energy consumption of the cars quite perfectly. It is noticed in general that while operating within the city of Indianapolis, the consumption per mile is greater than where the cars are running through the country. An increase in the slant of the consumption curves is also noticeable when the cars are running through Muncie at the end of the trip, but is not so pronounced as in Indianapolis. The cycle of events can be followed quite accurately in the case of most of the cars; for instance, taking train number 13 which consists of car number 254, we find that until it reaches siding 27, which is at the limits of Indianapolis, the rate at which energy is consumed is quite high; after leaving siding 27 the rate of consumption falls off somewhat, but increases again between sidings 25 and 24.

TABLE I.

Consumption per Car. East and West.

EAST BOUND.			WEST BOUND.		
Train.	Car No.	K.W.H.	Train.	Car No.	K.W.H.
		Local Cars.			
1	246	131.2	2	260	122.4
3	262	111.0	4	263	140.0
5	264	148.0	6	254	142.5
7	260	130.6	8	261	142.0
9	...	.....	10	...	.....
11	263	124.5	12	246	128.5
13	254	137.6	14	262	122.0
15	260	127.5	16	260	114.2
17	....	.....	18	...	.....
19	246	125.6	20	263	135.5
21	262	123.0	22	254	139.2
23	260	133.5	24	261	132.8
25	...	.....	26	...	.....
27	263	.....	28	246	134.8
29	254	162.0	30	262	127.0
31	261	146.5	32	252	139.5
33	...	.....	34	...	.....
35	246	119.0	36	264	141.5
37	262	112.5	38	260	128.5
39	252	128.7	40	263	134.0
41	254	119.0	42	254	126.0
43	263	118.5	44	252	113.1
	Min., 111.0 Ave., 129.2 Max., 162.0			Min., 113.1 Ave., 131.3 Max., 142.5	
		Limited Cars.			
9	250	107.4	10	255	101.0
17	255	96.0	18	250	123.8
25	250	108.5	26	255	106.0
33	255	101.0	34	250	119.6
	Min. 96.0 Ave., 103.2 Max., 108.0			Min., 101.0 Ave., 112.6 Max., 123.0	

TABLE II.

Train Log.

Train No.	Car No.	Direction.	K. W. H.	K. W. H. Per Car Mile.
1	246	East	131.2	2.32
12	246	West	128.5	2.28
19	246	East	125.6	2.21
28	246	West	134.8	2.38
35	246	East	119	2.11

TABLE II.—Continued.

Average, East				2.21
Average, West				2.33
9L	250	East	107.4	1.9
18L	250	West	123.8	2.19
25L	250	East	108.5	1.92
34L	250	West	119.6	2.11
Average, East				1.91
Average, West				2.15
39	252	East	128.7	2.27
32	252	West	139.5	2.46
44	252	West	113.1	2.00
Average, East				2.27
Average, West				2.23
6	254	West	142.5	2.52
13	254	East	137.6	2.43
22	254	West	139.2	2.46
29	254	East	162	2.86
41	254	East	119.0	2.10
42	254	West	126	2.23
Average, East				2.46
Average, West				2.40
10L	255	West	101.0	1.77
17L	255	East	96.0	1.70
26L	255	West	106.0	1.87
33L	255	East	101.0	1.78
Average, East				1.74
Average, West				1.83
2	260	West	122.4	2.16
7	260	East	130.6	2.30
15	260	East	127.5	2.25
16	260	West	114.2	1.85
23	260	East	133.5	2.35
38	260	West	128.5	2.27
Average, East				2.30
Average, West				2.09
31	261	East	156.5	2.59
8	261	West	142.0	2.51
24	261	West	132.8	2.34
Average, East				2.59
Average, West				2.42
30	262	West	127.0	2.24
3	262	East	111.0	1.96
14	262	West	122.0	2.15
21	262	East	123.0	2.17
37	262	East	112.5	1.98
Average, East				2.03
Average, West				2.19
11	263	East	124.5	2.20
20	263	West	135.5	2.39
27	263	East	94.5	2.48
40	263	West	134.0	2.37
43	263	East	118.5	2.09
4	263	West	140.0	2.48
Average, East				2.26
Average, West				2.41

TABLE II.—Continued

5	264	East	148.0	2.61
38	264	West	141.5	2.49

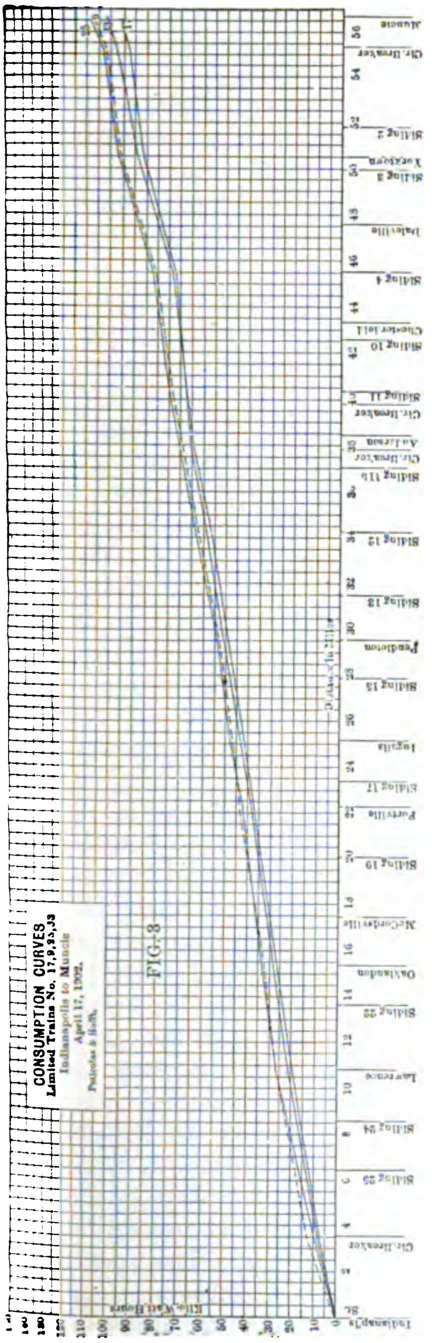
L indicates limited trains.

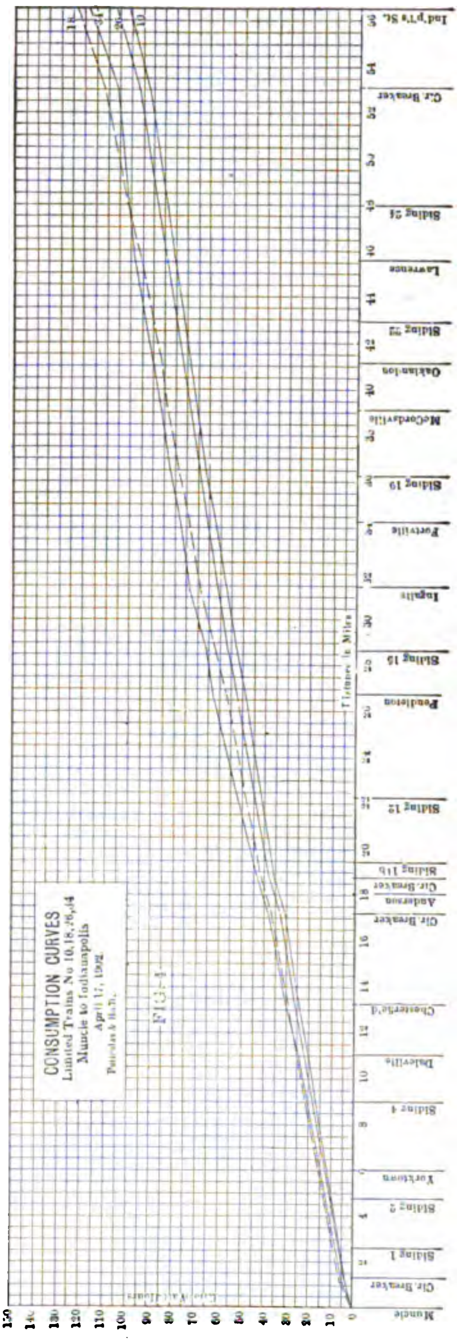
TABLE III.
LOCAL CAR NO. 260 EAST BOUND. K.W.H. CONSUMPTION

Station.	Distance	K.W H. Between Stations			W.K.H. per Car Mile		
	Miles.	Min.	Ave.	Max.	Min.	Ave.	Max.
Indianapolis.....							
	3.4	9.9	10.8	12.3	2.91	3.18	3.62
Indianapolis E. ..							
	7.4	18.9	19.1	19.2	2.55	2.58	2.60
Lawrence							
	11.4	18.3	22.8	27.1	1.61	2.00	2.38
Portville							
	2.8	7.2	7.9	9.0	2.57	2.82	3.18
Ingalls							
	4.7	7.0	7.9	9.0	1.49	1.68	1.82
Pendleton							
	8.0	16.8	18.1	18.9	2.10	2.26	2.36
Anderson W.							
	1.2	4.5	5.2	5.8	3.75	4.34	4.84
Anderson E.							
	6.5	9.5	11.7	13.8	1.46	1.80	2.12
Daleville.........							
	5.1	10.2	10.3	10.5	2.0	2.02	2.06
Yorktown							
	6.0	15.0	15.0	15.1	2.50	2.50	2.51
Muncie..........							
Indianapolis							
	56.5	117.3	128.8	140.6	2.07	22.8	2.48
Muncie..........							

TABLE IV.
LOCAL CAR NO. 260, WEST BOUND. K.W.H. CONSUMPTION.

Station.	Distance.	K.W.H. Between Stations			K.W.H. Per Car Mile.		
	Miles.	Min.	Ave.	Max.	Min.	Ave.	Max.
Muncie..........							
	6.0	11.8	13.7	15.1	1.97	2.29	2.50
Yorktown							
	5.1	7.3	11.0	16.0	1.43	2.15	3.14
Daleville.........							
	6.5	13.6	13.7	13.8	2.09	2.11	2.12
Anderson E.							
	1.2	2.5	3.7	4.5	2.08	3.08	3.76
Anderson W.							
	8.0	13.3	16.7	19.1	1.66	2.09	2.39
Pendleton							
	4.7	9.3	10.6	12.6	1.98	2.26	2.68
Ingalls.							
	2.8	5.1	5.8	6.9	1.76	2.00	2.38
Fortville							
	4.8	8.0	8.9	9.9	1.66	1.86	2.06
McCordsville......							
	6.6	13.5	14.6	16.6	2.05	2.21	2.53
Lawrence							
	7.4	12.8	14.1	16.4	1.73	1.91	2.22
Indianapolis E. ..							
	3.4	8.5	10.2	11.9	2.50	3.00	3.50
Indianapolis							
Muncie..........							
	56.5	105.7	123.0	142.8	1.87	2.18	2.52
Indianapolis							


CONSUMPTION CURVES
Limited Trains No. 17,9,23,33
Indianapolis to Muncie
April 17, 1902.
Potleelas & Roth.
FIG. 3
Kilo-Watt Hours
Distance in Miles
Indianapolis
Cir. Breaker
Siding 23
Siding 24
Lawrence
Siding 22
Oaklandon
McCordsville
Siding 19
Fortville
Siding 17
Ingalls
Siding 15
Pendleton
Siding 13
Siding 12
Siding 11½
Cir. Breaker
Anderson
Siding 11
Cir. Breaker
Chesterfield
Siding 10
Siding 4
Daleville
Siding 3
Yorktown
Siding 2
Cir. Breaker
Muncie
33
23
9
17


CONSUMPTION CURVES
Limited Trains No 10,18,26,34
Muncie to Indianapolis
April 17, 1902.
Potleelas & Roth.
FIG. 4
Kilo-Watt Hours
Distance in Miles
Muncie
Cir. Breaker
Siding 1
Siding 2
Yorktown
Siding 4
Daleville
Chesterfield
Cir. Breaker
Anderson
Cir. Breaker
Siding 11½
Siding 12
Pendleton
Siding 15
Ingalls
Fortville
Siding 19
McCordsville
Oaklandon
Siding 22
Lawrence
Siding 24
Cir. Breaker
Ind'p'l's St.
18
34
26
10

The car runs through Lawrence with relatively small energy consumption and continues at about the same rate until the western limits of Anderson are reached. In passing through Anderson there is quite a considerable increase in the energy consumption of the car. West of Anderson the rate of consumption returns to normal until siding 3 is reached where in working in and out of the siding a considerable amount of power is required. From siding 3 the car runs into Muncie under a normal amount of energy per car mile.

The schedule speed of local trains between Indianapolis and Muncie is 23 miles per hour; on clear stretches running through the country the speed frequently runs up to 50 miles per hour, but in general, averages about 38 miles per hour. In the towns, however, a slower rate of speed is required, which brings the schedule in the country to 27 miles per hour. When operating within the city limits of Anderson and Muncie 20 miles an hour are not, in general, exceeded, and in Indianapolis the rate varies from 20 miles in the suburbs to 10 miles in the business districts. The schedule speed in Indianapolis is 10.28 miles. The slower speeds within the towns together with the frequent stops made therein account for the greater consumption within city limits.

The curves of Fig. 2 show an improvement in the operation of the local trains going west, for the reason that the consumption curves bunch together much better and show a less variation from the mean.

What has just been said regarding local trains must be reversed in comparing the consumption curves of the limited trains, shown in Figs. 3 and 4. The curves for the limited trains running east on April 17th follow one another very closely and indicate but slight variations in the power consumption per car mile per train. In the case of the trains running west, however, the car consumption of train 34 is considerably higher than that of train 10, and variations in the rate of energy consumption are much greater in the case of the cars running west than in the case of those running east. The fact that the eastern limited trains are usually given right-of-way at the sidings, has much to do with these variations; the number of stops per trip of the west bound limited trains being in general in excess of the number of stops per trip of the east bound limited trains. The speeds attained by the limited trains run as high as 60 miles an hour. Speeds as high as 52 and 53 miles an hour are frequent.

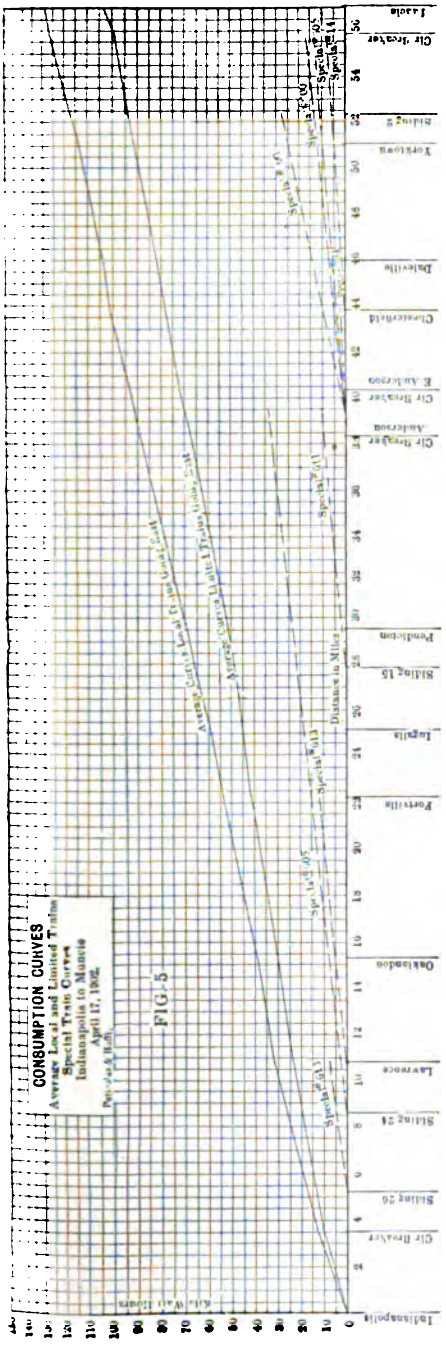

CONSUMPTION CURVES
Average Local and Limited Trains
Special Train Curves
Indianapolis to Muncie
April 17, 1902.
Peterson & Hoff.
Kilo-Watt Hours
Distance in Miles
Average Curve Local Trains Going East
Average Curve Limited Trains Going East
Special
Indianapolis
Cir Breaker
Siding 26
Siding 24
Lawrence
Oaklandon
Fortville
Ingalls
Siding 15
Pendleton
Cir Breaker
Anderson
Cir Breaker
E. Anderson
Chesterfield
Daleville
Yorktown
Siding 2
Cir Breaker
Muncie

FIG. 5

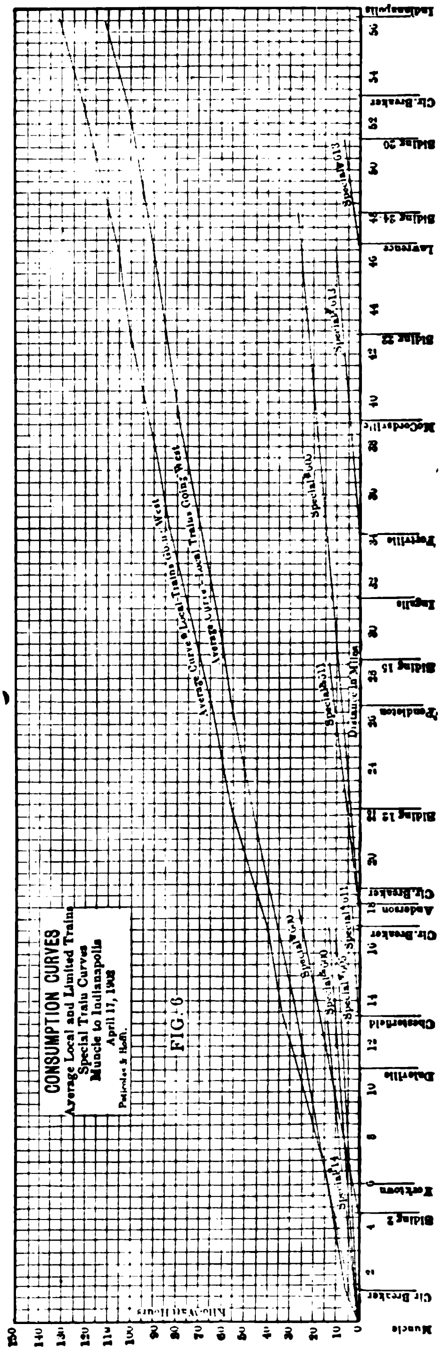

CONSUMPTION CURVES
Average Local and Limited Trains
Special Train Curves
Muncie to Indianapolis
April 17, 1902.
Peterson & Hoff.
Kilo-Watt Hours
Distance in Miles
Average Curve Local Trains Going West
Average Curve Limited Trains Going West
Special
Muncie
Cir Breaker
Siding 2
Yorktown
Daleville
Chesterfield
Cir. Breaker
Anderson
Cir. Breaker
Siding 14
Pendleton
Siding 15
Ingalls
Fortville
McCordsville
Siding 22
Lawrence
Siding 24
Siding 26
Cir. Breaker
Indianapolis

FIG. 6

The schedule speed is 28 miles an hour. Since cars have to cover the distance between Anderson and Muncie, which is 56.55 miles, in two hours, and as the limited trains consume 35 minutes in passing through city streets, the schedule speed in the open country is 35 miles an hour.

In Fig. 5 is shown a comparison between the power consumption of the local and limited trains; these curves are the average of all the local and limited trains operated on April 17th, going east from Anderson. The greater power consumption of the local trains is, of course, due to the fact that owing to the stops and the longer schedule, the local trains took two hours and a half to make the trip against two hours by the limited trains.

In Fig. 5 we have the consumption curves for the local and limited trains running west. It will be noticed that the curves in Fig. 6 lie closer together than those of Fig. 5. The total average car consumption of the local trains is the same in both instances, whereas the average consumption of the limited trains running east is less than that of the limited trains running west.

In Figs. 5 and 6 are also shown the consumption curves of special trains which were operated on the day mentioned. These give a good idea of the amount of service rendered which is not included in the regular daily schedule. The special or work-trains were run over the system while the test was in progress. The cars were all small and did not consume a great deal of power; they were not equipped with wattmeters, and hence only an approximation could be made of the amount of energy they consumed.

It is quite hard to determine just why the different cars will make the run between Indianapolis and Muncie in practically the same time, and on different runs consume such different amounts of energy

The trains scheduled in Table I. have been grouped together in Table II. so that a comparison can be made of the kilowatt hour consumption of different runs. We find, for instance, that car 254 made one trip east consuming 162 k.w.h. and another consuming 119 k.w.h. which is a difference of 36 per cent. The western trips on the same day showed a maximum consumption of 142 k.w.h. and a minimum of 126 k.w.h., a difference of only 13 per cent. Of all the trains scheduled in Table II., car 262 made the trip east with the least energy consumption, requiring but 111 .k.w.h., which is at the rate of 1.96 k.w.h. per car mile. The highest consumption by this car is 123 k.w.h., or an increase of only 10 per cent. The number of stops made by a car on different trips undoubtedly has quite an effect upon the amount of energy consumed. The greater the number of stops the greater the amount of time deducted from the regular running time, and, the greater must be the acceleration of the train to enable it to make up the lost time. This is quite clearly brought out by the fact that the limited trains, as shown in Table I., average on their eastern trips only 103 k.w.h., whereas the local trains average 129 k.w.h. on their eastern trips, an increase of 35 per cent. As a rule the limited trains after leaving Indianapolis only stop once at Anderson in their run to Muncie. Going west the limited trains usually pull in at sidings to allow east bound trains to pass. This probably accounts for the fact that the k.w.h. consumption of the west bound limited trains is somewhat greater than the k.w.h. consumption of the east bound limited trains, although the west bound limited trains are relatively running down grade, Muncie having an elevation of about 100 feet above Indianapolis.

The number of stops made by the local cars outside of the cities averages about 34.

An average taken of the runs made by the local cars, east and west, shows them to be very much the same. For instance, in Table I., the average of the east bound locals is 129 k.w.h. and of the west bound, 131, k.w.h.; practically the same.

The best run going east shows a car consumption of 111 k.w.h. by car number 262; the highest car consumption going east is 162 k.w.h. by car number 254, a difference of 49 per cent. The average of the eastern trips made by car number 262 is 115 k.w.h., and the average of the trips made by car 254 is 139 k.w.h., a difference of 21 per cent. As the two cars are of the same weight and equipment, and as the runs made by them are spaced sufficiently close together to admit of the supposition that the average stops made during the day by the two cars is very much the same, we have to assume that the difference in power consumption is caused by the equipment of car number 262 being in better condition than that of car number 254 as the personal equation of the motorman in the operation of his car in local interurban service, as will be shown later, is practically without effect where a number of runs are taken into consideration. Among the west bound local trains, car 254 shows again the highest consumption, which seems to make it quite conclusive that its running gear was affected in some particular. Here we have a case in point in which causes other than the number of starts made during a trip having had the effect of causing a decided increase in the power consumption of a car. We cannot, therefore, charge up discrepancies in energy consumption entirely to the number of starts made. It is fair to say, however, that each start requires the expenditure of from .5 to .8 k.w.h.

In the case of the limited runs we find by reference to Table I. a variation of 13 per cent. in the energy taken by the east bound trains and a variation of 22 per cent. in the energy taken by the west bound trains.

In connection with the general discussion of the amount of power required to operate these trains it has been thought of value to study the results obtained from the operation of a given car over a series of trips in detail. Car 260 has accordingly been made the subject of this analysis. From Table II. it will be noticed that car number 260 made six local trips between Indianapolis and Muncie, three east and three west, on April 17th, which are distributed entirely through the day. The car may therefore be assumed to represent fairly well the average daily cycle through which a local car has to pass.

In Tables III. and IV. the analysis of the performance of this car is presented. In Table III. the column which shows the average k.w.h. consumption between stations gives the average energy consumption of the car for the three trips made from Indianapolis to Muncie. The column to the right of this headed " maximum " gives the maximum consumption between the different stations that occurred in any one of the three eastern trips and the column headed " minimum " gives the minimum consumption that occurred on any one of the three trips east to operate the car between the stations.

The "average" column may therefore be said to represent the average daily performance of the car. The "maximum" column gives the probable amount of power which the car is likely to use in passing between stations and the "minimum" column gives what is probably the least amount of energy which this car is likely to take in passing between stations, in local service. The footings of these columns give accordingly the probable maximum, the average ordinary and the probable minimum energy which the car will take in making a trip from Indianapolis to Muncie.

The maximum, 140.6 k.w.h., is 9 per cent. in excess of the average and 12 per cent. in excess of the minimum. The greatest differences between the maximum and minimum values occur in the runs between Lawrence and Fortville, and Anderson

E. and Daleville. The variations between the maximum and minimum values between Daleville and Muncie are relatively immaterial. In running between Lawrence and Fortville the maximum value is 47 per cent. in excess of the minimum and in running from Anderson E. to Daleville the maximum is 45 per cent. in excess of the minimum.

The average for the trip (in Table III.) is 128.8 k.w.h. The average of the three actual eastern trips of car 260 given in Table II. is 130.5, showing that the sum of the average energy consumptions of several runs taken between stops is 1.5 per cent. less than the actual average of the three runs. In Table IV. a similar set of tabulations is made for the three west bound trips of car 260 and results that do not markedly differ from those of Table III. are shown. For instance, the average energy consumption in Indianapolis east bound is 10.8 k.w.h. against 10.2 west bound. The average energy consumption in Muncie is 15 k.w.h. east bound against 13.7 west bound. The average energy consumption in Anderson is 5.2 east bound against 5.1 west bound.

The greatest difference in the averages is shown in those taken for the runs between Indianapolis E. and Lawrence; the average of the east bound trains, 19.1 k.w.h., being 49 per cent. in excess of the average of the west bound trains between these points. The greatest variations between the maximum and minimum consumption between stations in Table IV. occurs in the runs between Yorktown and Daleville, where the variation is 119 per cent.

As regards the energy consumption for the trip, we find that the average of the east bound trains exceeds the average of the west bound trains by 4.5 per cent.; and that the maximum probable energy consumption of east bound trains is 142.8 k.w.h., which is 35 per cent. in excess of the minimum and 16 per cent. in excess of the average.

The three columns at the left of Tables III. and IV. refer to the consumption of car 260 in k.w.h. per car mile.

It is noticeable that the maximum rate of energy consumption in all cases occurs in the cities. The energy consumption per car mile in Anderson being greatest, in Muncie least and in Indianapolis more or less of an average between the other two places. This increase in the energy consumption in the cities is due to the slower speeds, frequent stops and very often to low voltage. It will be noticed that the maximum energy consumption in Anderson is 4.84 k.w.h. per car mile, whereas in Indianapolis it is only 3.62 k.w.h. per car mile.

TABLE V.

Local Car Consumption for Various Sections of Line. East Bound.

Station.	Distance	K.W.H. Between Stations.			K.W.H. Per Car Mile		
	Miles.	Min.	Ave.	Max.	Min.	Ave.	Max
Indianapolis							
	3.4	9.4	11.9	14.6	2.76	3.50	4.30
Indianapolis E.							
	7.4	13.8	18.9	25.5	1.86	2.55	3.45
Lawrence							
	11.4	13.7	22.8	29.0	1.20	2.00	2.55
Fortville							
	2.8	5.2	7.1	8.1	1.86	2.53	2.89
Ingalls.							
	4.7	7.0	9.5	12.5	1.49	2.02	2.66
Pendleton							
	8.0	16.1	19.8	24.1	2.01	2.47	3.01
Anderson W.							
	1.2	4.0	5.3	8.2	3.40	4.42	6.82
Anderson E							
	6.5	9.0	12.4	17.2	1.38	1.91	2.65
Daleville							
	5.1	7.0	8.7	12.2	1.37	1.71	2.39
Yorktown							
	4.7	7.4	10.4	12.3	1.57	2.21	2.61
Muncie W.							
	1.3	2.5	5.2	9.9	1.92	3.99	7.60
Muncie							
Total Trip	56.5	95.1	132.0	173.6	1.68	2.34	3.06
Total Urban	5.9	15.9	22.4	32.7	2.70	3.79	5.54
Total Interurban	50.6	79.2	110.4	140.9	1.56	2.18	2.79

TABLE VI.

Local Car Consumption for Various Sections of Line. West Bound.

Station.	Distance.	K.W.H. Between Stations.			K.W.H. Per Car Mile.		
	Miles.	Min.	Ave.	Max.	Min.	Ave.	Max.
Muncie							
	1.3	2.5	5.2	9.9	1.92	3.99	7.6
Muncie W.							
	4.7	7.8	10.8	15.3	1.66	2.29	3.25
Yorktown							
	5.1	7.3	13.1	16.8	1.43	2.57	3.29
Daleville							
	6.5	9.2	13.7	15.7	1.42	2.10	2 42
Anderson E.							
	1.2	2.5	4.4	6.1	2.08	3.66	5.09
Anderson W.							
	8.0	15.4	19.2	23.3	1.93	2.40	2.92
Pendleton							
	4.7	7.0	10.6	15.0	1.49	2.26	3.19
Ingalls							
	2.8	5.1	6.6	8.4	1.82	2.35	3.00
Fortville							
	11.4	17.0	24.2	28.5	1.49	2.12	2.50
Lawrence							
	7.4	12.0	15.5	22.3	1.67	2.15	3.10
Indianapolis E.							
	3.4	7.5	11.5	18.6	2.21	3.38	5.47
Indianapolis							
Total Trip	56.5	93.3	134.9	179.9	1.65	2.37	3.18
Total Urban	5.9	12.5	21.1	34.6	2.12	3.57	5.88
Total interurban	50 6	80.8	113.8	145.3	1 60	2.24	2.87

The least energy consumption per car mile shown in these tables is on one of the westward trips between Yorktown and Daleville, where as low a value as 1.43 k.w.h. per car mile is shown. This is but 30 per cent. of the maximum consumption cited for the eastern trip in Anderson.

In Tables V. and VI. a still more elaborate study has been made of power consumption between points. These tables include a resumé of all of the data accumulated for all of the cars on April 17th. For instance, the table of east bound consumption gives in the average column the average consumption between points for all of the cars, the minimum column gives the least consumption recorded between points for any one of the cars and the maximum gives the maximum consumption for any one of the cars.

Comparing these results we see that in running through Muncie the power consumption per car mile varies from 2.5 to 9.9, a variation of 300 per cent. Differences exceeding 100 per cent. are quite frequent, as for instance between Indianapolis E. and Lawrence and between Lawrence and Fortville and in Anderson. Since all of the cars are of about the same weight and equipped in the same way, it is quite evident that even in the local runs much could be done to improve the character of the operation, especially if the motormen were carefully instructed in the detail handling of their cars.

The values given in the maximum column are the exceptionally high values. They reach a total of 173.6 k.w.h. This value is in excess of any of the east bound trips given in Table I. and is even higher than the power required by car 254 in trip 29, which is in itself 25 per cent. higher than the average of all the eastern trips for that day. The run of car 254 indicates the degree to which very bad conditions are sometimes approximated. Any motorman who should continually operate his car making a demand as high as the maximum values given in Tables V. and VI., that is 173 to 180 k.w.h. per trip, should be discharged.

The minimum value per trip given in Table V. of 95.1 k.w.h. is 16.5 per cent. less than the minimum for any local trip in Table I. and is even 1 per cent. less than the minimum consumption, 96 k.w.h., made in the best eastern trip of a limited car. Ninety-five k.w.h. is therefore probably less than the minimum value that any car will ever take in a local trip between Indianapolis and Muncie. This is 49 per cent. less than the average and 83 per cent. less than the maximum k.w.h. consumption per trip given in Table V. In all of the values given in Table V. it is quite noticeable that the difference between the minimum and the average is less than the difference between the average and the maximum. This indicates that the motormen, in general, handle their cars creditably.

The composite presentation of the data of all west bound trains given in Table VI. tells much the same story as does Table V. The best performance per trip of 93.3 k.w.h. betters the best performance of Table V. as does also the best performance of car 260 west bound better its best performance east bound. In the same way the maximum of 179.9 k.w.h. is greater than the maximum for the total trip of Table 5. Car 260 shows this same result; the western maximum per trip being 2 k.w.h. larger than the eastern maximum per trip.

There would therefore seem to be something in the contour of the road which develops greater irregularities in operation when cars are running west than when they are running east. These conditions are not very marked yet sufficiently so to be noticeable. They cannot be traced especially to the cities as against interurban operation. At the bottom of Tables V. and VI. the urban and interurban power consumption is separated and for all of these results the minimum and maximum values of Table VI. are respectively less and greater than the minimum and maximum values of Table V.

The urban and interurban data, however, bring out very clearly the fact that within the city limits the car consumption per car mile is considerably greater than in running through the country. The maximum values for city service run as high as 7.6 k.w.h. per car mile and average 5.88 k.w.h., whereas in the country the maximum value either east or west does not exceed 3.45 k.w.h. per car mile and average not more than 2.87 k.w.h. per car mile. The values given in the column of averages show best the relative performance of cars in urban and interurban service. During the east bound trips the urban cars on the average consumed 17 per cent. of the energy running 10.4 per cent. of the distance, their power consumption in the cities per car mile being on the average 74 per cent. in excess of what it was in the country.

In Table VI. it is shown that while running but 10.4 per cent. of the distance in the cities, the west bound trains consumed 15.5 per cent. of the energy; their car mile consumption being 60 per cent. higher in urban than in interurban service. To make the comparison between the average energy consumption of the cars when east and west bound more complete; the average values are brought together in Table VII. This table shows that trains running east and west require approximately the same power when running through the cities, the greatest variations occurring in the interurban service. The run between Dalcville and Yorktown is most noticeable in this respect, power consumption going west being 43 per cent. greater than the average power consumption of trains going east. The general averages given at the bottom of the page show quite clearly that the local trains require under average conditions the same amount of power whether running eastward or westward.

Passing from the local trains, we have gathered together in Tables VIII., IX. and X. a comparison of the performance of all the limited trains in service. The most noticeable thing in connection with the data here given is that the variations in the energy consumption per trip in the limited service are very much less than those in the local service. As between the different runs by limited cars, the tables show again that the differences in the consumption of east bound trains are less than the differences in the consumption of west bound trains. It will be remembered that the same notation has been made in discussing the performance of car number 260 as that of all the local trains. The minimum possible energy consumption per trip whether east or west is 95 k.w.h., or practically the same as that given for the local trains. The fact that the limited runs show up so much better than do the local runs is undoubtedly due to the number of starts in the limited trips being very much less, the limited cars having the right-of-way and the best motormen being in charge of them. These three items taken collectively account for a great deal.

It will be noticed by reference to Table VIII. that the energy consumption by cars between Indianapolis East and Anderson West is practically the same and that there is but 25 per cent. difference in the energy consumption when the cars are running between Anderson East and Muncie West. It must be remembered that this percentage indicates the maximum difference that occurred between any two cars at any time.

The variation in the energy consumption of the cars running through the cities does not vary in excess of 50 per cent. between the maximum and minimum values. Whereas, it will be remembered that in the case of the local cars, differences as great as 300 per cent. are recorded. The maximum urban consumption per

TABLE VII.

(See Tables V. and VI.)

COMPARISON OF AVERAGE LOCAL CAR CONSUMPTION OVER CERTAIN SECTIONS OF THE LINE.

Section.	Distance Miles.	Average Consumption.			
		K.W.H. Between Stations		K.W.H. Per Car Mile.	
		East.	West.	East.	West.
Indianapolis	3.5	11.9	11.5	3.50	3.38
Indianapolis E.	7.4	18.9	15.5	2.55	2.15
Lawrence	11.4	22.8	24.2	2.00	2.12
Fortville	2.8	7.1	6.6	2.53	2.35
Ingalls.	4.7	9.5	10.6	2.02	2.26
Pendleton	8.0	19.8	19.2	2.47	2.40
Anderson W.	1.2	5.3	4.4	4.42	3.66
Anderson E.	6.5	12.4	13.7	1.91	2.10
Daleville............	5.1	8.7	13.1	1.71	2.37
Yorktown	4.7	10.4	10.8	2.21	2.29
Muncie W.	1.3	5.2	5.2	3.99	3.99
Muncie.............					
TOTAL TRIP	56.5	132.0	134.0	2.34	2.37
TOTAL URBAN	5.9	22.4	21.1	3.79	3.57
TOTAL INTERURBAN .	50.7	110.4	113.8	2.18	2.24

TABLE VIII.

LIMITED CAR CONSUMPTION FOR VARIOUS SECTIONS OF LINE. EAST BOUND

Station.	Distance Miles.	K.W.H. Between Stations			K.W.H. Per Car Mile.		
		Min.	Ave.	Max.	Min.	Ave.	Max.
Indianapolis	3.4	8.1	8.7	10.3	2.38	2.56	3.03
Indianapolis E. ..	34.4	56.5	58.0	59.9	1.64	1.69	1.74
Anderson W.	1.2	3.4	4.2	4.8	2.84	3.50	4.00
Anderson E.....	16.3	24.0	28.5	30.6	1.47	1.75	1.88
Muncie W.	1.3	3.0	3.6	4.4	2.31	2.77	3.38
Muncie..........							
TOTAL TRIP	56.6	95.0	103.0	110.0	1.68	1.82	1.94
TOTAL URBAN ...	5.9	14.5	16.5	19.5	2.46	2.80	3.30
TOTAL INTERURBAN	50.7	80.5	86.5	90.5	1.59	1.71	1.79

TABLE IX.

Limited Car Consumption for Various Sections of Line. West Bound.

Station.	Miles	K.W.H. Between Stations.			K.W.H. Per Car Mile.		
		Min.	Ave.	Max.	Min.	Ave.	Max.
Muncie..........							
	1.3	3.5	4.4	5.1	2.49	3.38	3.92
Muncie W.							
	16.3	27.1	29.9	32.3	1.66	1.83	1.98
Anderson E.							
	1.2	3.9	4.6	5.3	3.25	3.84	4.42
Anderson W.							
	9.9	16.9	19.6	22.8	1.71	1.98	2.31
Siding 15.........							
	7.6	13.5	14.9	16.5	1.78	1.96	2.17
Siding 19.........							
	16.8	16.7	25.0	33.0	.99	1.49	1.96
Indianapolis E. ..							
	3.4	8.9	11.2	13.9	2.61	3.29	4.09
Indianapolis							
Total Trip	56.5	90.5	109.6	128.9	1.60	1.94	2.28
Total Urban ...	5.9	16.3	20.2	24.3	2.76	3.60	4.12
Total Interurban	50.6	74.2	89.4	104.6	1.47	1.77	2.07

TABL X.

(See Tables 8 and 9.)

Comparison of Average Limited Car Consumption over Certain Sections of the Line.

Section.	Distance Miles.	Average K.W.H. Consumption.			
		K.W.H. Between Stations		K.W.H. Per Car Mile.	
		East.	West.	East.	West.
Indianapolis					
	3.4	8.7	11.2	2.56	3.29
Indianapolis E.					
	34.4	58.0	59.5	1.69	1.73
Anderson W.					
	1.2	4.2	4.6	3.50	3 84
Anderson E..					
	16.3	28 5	29.9	1.75	1.83
Muncie W.					
	1.3	3.6	4.4	2.77	3.38
Muncie.............					
Total Trip	56.5	103.0	109.6	1.82	1.94
Total Urban	5.9	16.5	20.2	2.80	3.60
Total Interurban .	50.6	86.5	89.4	1.71	1.77

TABLE XI.

Personal Factor of Motormen.

Local Runs.

Name.	East. Total K.W.H.			West. Total K.W.H.			Trips.	
	Min.	Average	Max.	Min.	Average	Max.	East.	West.
Eller...........	122	135	148	114	125	136	6	6
Lee............	116	121	126	124	129	130	4	4
Robbins........	122	131	138	119	124	128	4	4
Green..........	113	123	131	126	134	141	3	3
Young	118	122	128	112	128	145	3	6
Griffin	124	130	140	127	131	134	3	4
Embry..........	108	126	154	134	135	135	3	2
		127			130		26	29

TABLE XI.—Continued.

Limited Runs.

Name	Total K.W.H.			Trips.
	Min.	Average.	Max.	
Motsie	101	109	115	13
Frazier	95	101	104	12
		105		25

TABLE XII.

Local Run of Car 237

Station.	EAST BOUND.				WEST BOUND.			
	Starts.	(A) K.W.H. Per Car Mile.	(B) Sq. Root Mean Sq Cur.	*Ratio. B — A	Ratio C — D	(C) Sq Root. Mean Sq. Cur.	(D) K.W.H Per Car Mile.	Starts
Indianapolis ..								
	12	3.27	49.6	21.9	14.6	49.5	3.39	12
Siding 27								
	5	2.83	53.1	18.8	....	....	....	6
Lawrence .. .								
	3	2.63	53.1	20.2	....	....	1.48	1
Oaklandon ...								
	1	2.12	46 9	22.1	....	....	3.01	2
McCordsville...								
	2	1.91	43.1	22 6	....	....	3.15	5
Fortville								
	2	2 49	51.1	20.5	23.9	34.7	1.45	1
Ingalls.								
	3	2.39	49.2	20.6	20.1	44.0	2.19	5
Pendleton								
	5	2.29	49.0	21.4	21.9	47.2	2.16	5
Anderson....								
	7	2.98	50.4	16 9	23.7	55.0	2.32	3
Chesterfield....								
	1	1.50	36.1	24.0	22.4	57.0	2.53	2
Daleville.. ...								
	1	1.90	41.4	21.8	23.2	54.8	2.36	2
Yorktown								
	8	2.84	48.9	17.2	20.2	54.3	2.69	4
Muncie.......								
TOTAL TRIP...	50	2.48	48.9	19.7	21.6	49.0	2.27	48

K.W.H. per ton mile 85 6 .... 78.3
K.W.H. per trip 140.2..118.3

An allowance of 45 passengers is made per trip. at an estimated weight of 3.00 tons.

*The ratio B or C D is the "running factor" which multiplied by the K.W.H per car mile gives the square root of the mean square value of the current flowing in the motor armature. The square root of the mean square value of the running current is the value of the current to be used in a shop test.

car mile by the limited cars is 4.42 k.w.h. against 5.88 by the local cars. The best urban performance shown by the limited cars is 2.31 k.w.h. per car mile against 2.92 k.w.h by a local car. The best average urban consumption for the limited cars is 2.8 k.w.h. on east bound trips against 3.79 k.w.h. by the local cars. In general, therefore, at all points, the limited cars show better handling, more uniform records, and records which are much lower than the average of the local car performance. Occasionally, however, as is pointed out, a car in local service will show a better record over a short distance than will the limited cars.

The comparison of limited east and west bound trains given in Table X. shows little difference between them. The consumption of the west bound trains is uniformly slightly higher than that of the east bound. This is a distinct characteristic of the traffic over this system, as has already been pointed out.

Another interesting phase of this subject is brought out by the results which are given in Table XI. Here we have the work of the different motormen given in terms of the minimum, average, and maximum energy consumption of the cars in their charge during the three days of the general test. The best trip going east shows an energy consumption of 108 k.w.h., which is 43 per cent. less than the highest car consumption, recorded 154 k.w.h. It is interesting to note that these minimum and maximum records were made by the same man, the average of his three trips, however, is 126 k.w.h., which differs but by one per cent. from the average of all of his east bound trips. These results more than any others, bring out the fact that the variations in the energy consumption in local service are chiefly due to conditions existing at the time of specific runs. The average of the first man going east is 8 per cent. higher than his average going west. The average of the second man going east is 6.5 per cent. less than his average going west. The third man shows the greater consumption on his east bound trips; the fourth man the greatest on his west bound trips, and, so on for the others. Apparently, a motorman who so operates his car as to produce a greater energy consumption on his eastern trips than on his western, does so consistently, possibly, through some personal idea as to the way in which his car should be conducted over different portions of the road. For instance, the first man's minimum, average, and maximum is less on his western trips than on his eastern; in the same way the work of the second man shows that on his eastern trips his minimum, average, and maximum were consistently less than the minimum, average, and maximum on his western trips. This condition holds true for five out of the seven men reported as operating local cars. On the west bound trips, Young made his minimum trip with 112 k.w.h., which is the least of all, and his maximum trip was 145 k.w.h., which is the highest of all. Here again we have the same man making the best and the worst record, due in this case, probably, as in others to local conditions existing at the time. From observation of the way in which different motormen handled their cars, it seemed that where indicating instruments were mounted on a car, the general energy consumption of the car improved. The ammeters, voltmeters and recording wattmeters had not long been placed in the cabs of the different cars before the motormen began to study the behavior of their cars with different conditions of starting, and rivalry sprang up among them which was very gratifying to notice, each man trying to make his runs with the least amount of energy consumption and the least maximum current indicated by his ammeter. For this reason it is believed that the results which are here reported show a performance over this system quite up to, if not better, than the usual performance, owing to the fact that the men were so quick to take advantage of the new conditions. The test on the first day of the general series, April 17th, has been presented here for the reason that the men were less accustomed to the instruments and therefore working more nearly under their usual habit. They were given no instructions whatever for the handling of their cars and any change which they may have made in operating them was entirely due to their own ideas in the premises. In the case of the limited runs, results are given for but two men; however, they are sufficiently great in number to indicate quite accurately the character of their performance. Frasier produced results with a less consumption of power than did Motsie, his maximum and minimum being nearer his average than in the case of Motsie. This would seem to indicate that whereas in the case of any one man conditions existing at the time of a run to a great extent modify the power consumption of the car, nevertheless, a given man may be able to operate his car under the same conditions as some other man with a less energy consumption. These differences can be more readily detected in the case of the limited runs than in the case of the local runs, for the reason that variables other than those of the personality of the motorman are to a greater extent eliminated; the stops are less frequent, the speeds more uniform and conditions altogether less subject to change during different runs.

SPECIAL CAR TESTS.

The special car tests were undertaken with the special object in view of ascertaining as to how nearly the car equipments were being worked up to their rated capacity, inasmuch as the heating of a motor, performing a given character of work, has all to do with its capacity for accomplishing a greater or lesser amount of this work. The first point to be considered in connection with such tests is the arranging of adequate means for accurately determining the cycle of current fluctuations and the temperatures of the windings and cores. In street railway service motors are subjected to more variable conditions than are ordinarily to be found in industrial plants, and, consequently it is very much more difficult to predict the exact effect upon the motor of operating it for propelling a car over a given road than it is to predict the capacity of a motor for the handling of a certain load in stationary practice.

To equip a car to make the necessary instrumental observations is no small task. In the case of the present tests, the desired result was accomplished only after the experimenters had experienced considerable trouble and overcome many obstacles.

In all, three cars were tested; numbers 237, 252 and 255. Car number 237 has a total weight of 51,650 pounds, 38,150 pounds being in the car body, trucks, etc., and 13,500 pounds being in the electrical equipment; all of this weight came directly on the driving wheels. As these cars are always operated in the same direction and have, therefore, the controlling apparatus stationed at the forward end, this end weighed 650 pounds more than the rear end. The motors of this equipment were geared in the ratio of 30:52; the car wheels having a diameter of 32⅞ inches. The car, as equipped, has a length of about 40 feet. This type of car is used by the Union Traction Company chiefly on its northern lines between Anderson, Marion and Elwood.

Car number 252 is of a type more common on this system and has, in fact, already been described in part. It is 52 feet 6 inches long. Its weight is 63,100 pounds, of which 50,300 pounds is in the car body, motor truck, etc., and 12,800 in the electrical equipment. Of this weight 40,300 pounds was carried on the driving wheels. The motors were geared with a ratio of 20:51: the wheels being 34⅛ inches in diameter.

Car number 255 is similar to car number 252 except that the ratio of the gearing has been changed from 20:51 to 23:48. The object of this change in the gearing was to determine the effect upon the motors of working them up to a higher capacity and in improving the schedule of operation of the cars.

In conducting the tests, each of the cars was in turn equipped with a Thompson indicating wattmeter placed in the main circuit to indicate the power consumption. A specially calibrated Thompson wattmeter was in addition arranged to indicate the power lost in the field of one of the motors. The object of so arranging this instrument was to enable a determination to be made of the square root of the mean square value of the current. In the case of each of the motors this instrument was adjusted to meet the special requirements.

For ascertaining the speed of the car a small magneto generator was used belted to the car axle in connection with a calibrated voltmeter. In addition, definite determinations were also made of the instantaneous value of the current, of the line voltage and of the voltage at the terminals of one of the motors. Readings were taken continuously during any one trip, the trips extending from Indianapolis to Muncie going east and from Muncie to Indianapolis going west.

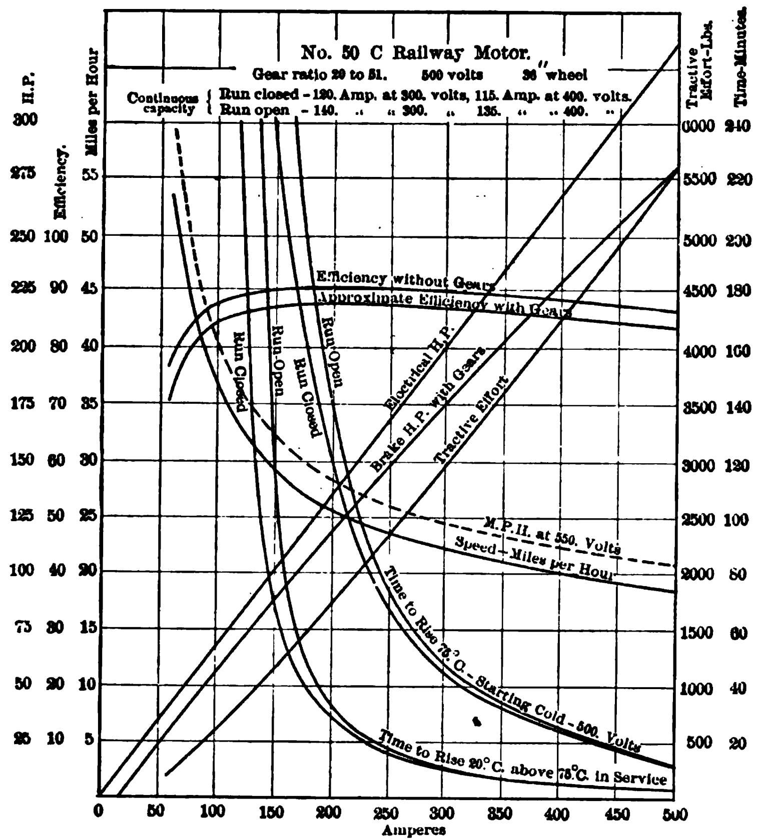
The cars were kept in the usual service of the road and an effort made to prevent the tests from interfering in any way with the normal operation of the cars. During times of acceleration or retardation, records were made at intervals of about five seconds, but at times of uniform speed the intervals between readings were made of a longer duration, from fifteen to twenty seconds.

Temperature measurements were made both by the increase in resistance method and with thermometers. The temperature measurements, however, were successful only to the extent of determining the effect of the degree of average work to which the motors were subjected.

In discussing the tests no attempt will be made to review the results in detail further than is necessary to bring out certain points which are deemed of interest in connection with the performances of cars.

As of the motors tested those of cars 252 and 255 are most important, their characteristics are given in Fig. 7. These motors are of the type No. 50 C, rated at 150 h.p.

The running logs of cars 252 and 237, which were tested in the spring of 1902, are given in Figs. 10, 11 and 12, and also in Tables numbered from 12 to 18. Table 12 is a summary of the results of a test made upon car 237 in local service. From this data it will be noted that columns A and D give the k.w.h. per car mile, and contain values which do not differ materially from the averages of Tables V. and VI. The east bound run shows an average consumption per car mile of 2.48 k.w.h. and the west bound run an average of 2.27.



Curve No. 2519 W.E. & M. Co. 6-19-01.

FIG. 7.

In columns B and C are given the determinations of the square root of the mean square value of the current in the motors between stations and for the total trip. The column headed " ratio of B/A " gives the ratios of the data in column B to that in column A. In the same way the column headed " ratio C/D " gives the ratios of the values in column C to the values in column

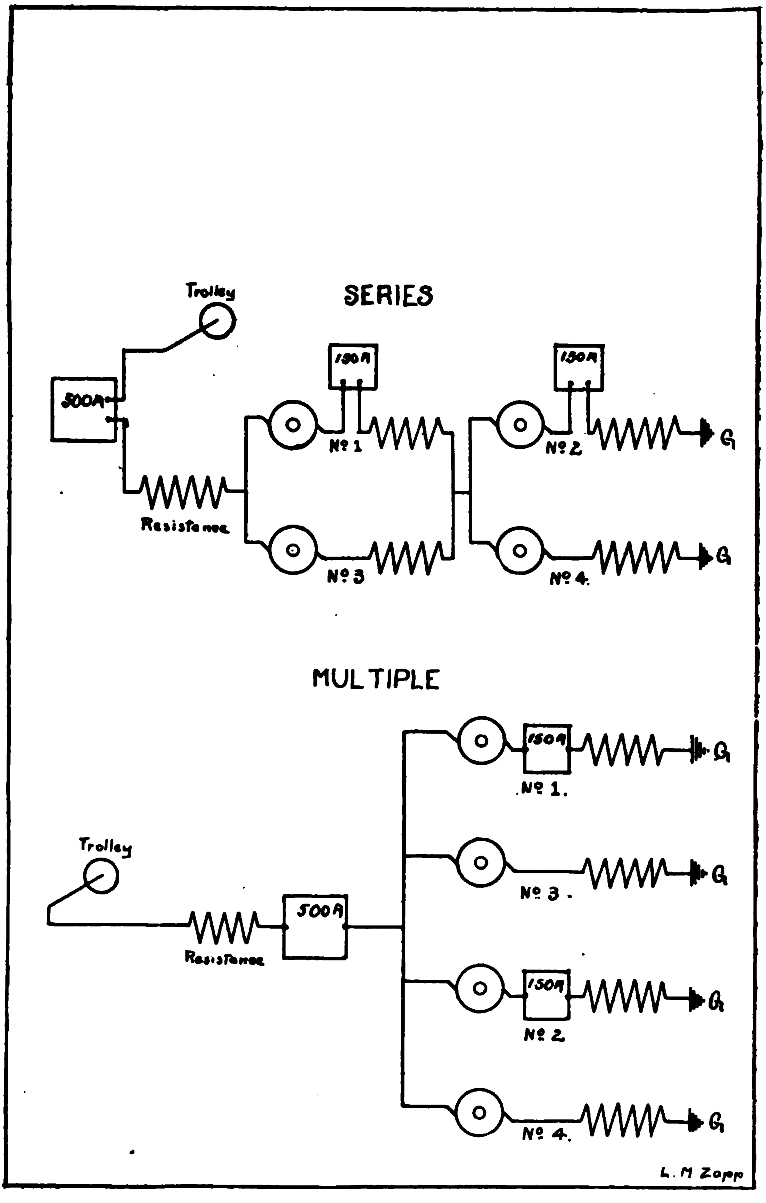


FIG. 8.—Motor Diagram, Car No. 237.

D. That is, these columns give the ratio of the square root of the mean square current to the k.w.h. per car mile. These ratios give an indication of the proportional heating effect of the power delivered from the feeders under the variable conditions of operation.

For present purposes, since the weights of the cars are known, the ratio taken between the square root of the mean square current and the car mile consumption gives an estimate of what may be termed the running-factor of the car equipment. Should the ratio be taken between the square root of the mean square of the current and the k.w.h. per motor mile, the value obtained may be termed the running-factor of a motor. The latter value is best adapted to purposes where it is desired to make comparisons of a large number of motor equipments.

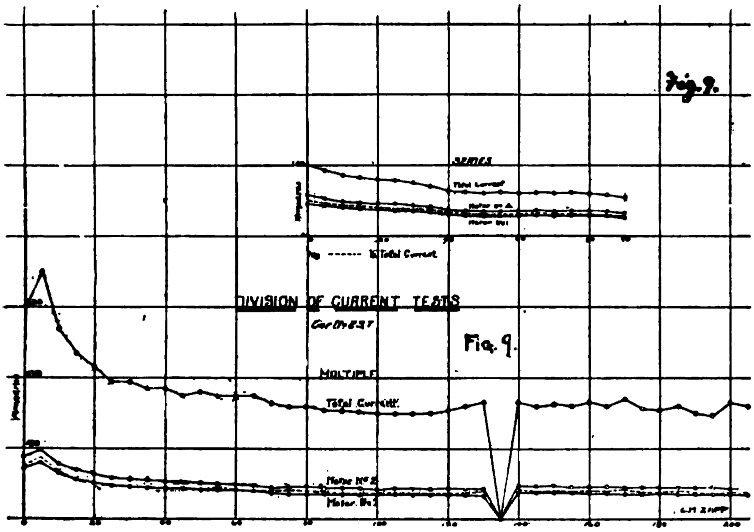


Fig. 9.

In the present instance it will be noticed that the running-factors of Table XII. do not vary greatly in value; they remain almost constant for runs between towns which may be considered as presenting anything like similar conditions of operation.

In Table XIII. we have a similar accumulation of data for a complete round trip made by car 252. Here the ratios are much more variable than are those in Table XII. This is due to the fact that on this particular run car 252 was subjected to a very unusual schedule, as in all 62 stops were made. The ratios of the west bound run are much more constant than

TABLE XIII

LOCAL RUN OF CAR 252.

Station.	EAST BOUND.				WEST BOUND.			
	Starts.	(A) K.W.H. Per Car Mile.	(B) Sq. Root Mean Sq. Cur.	Ratio. B — A	Ratio. C - - D	(C) Sq. Root Mean Sq. Cur.	(D) K.W.H Per Car Mile.	Starts
Indianapolis ..	8	4.20	97.5	23.2	33.0	85.5	2.59	7
Siding 27......	8	3.45	106.0	30.7	38.0	89.0	2.34	3
Lawrence	5	3.32	107.2	32.3	39.6	78.0	1.97	1
Oaklandon . .	2	2.63	97.9	37.2	41.7	82.5	1.98	3
McCordsville...	3	6.30	95.0	15 0	41.0	97.0	2.37	4
Fortville	3	1.72	98.4	57.2	36 2	91.9	2.54	2
Ingalls	2	5.78	124.0	21.5	36.7	81.8	2.32	2
Pendleton	14	5.17	109.0	21.1	34.4	87.5	2.55	8
Anderson.....	6	3.52	98.9	28.1	46.7	95.8	2.05	4
Chesterfield....	2	2.74	128.0	46.7	36.9	86.0	2.33	1
Daleville......	3	2.82	73.9	26.2	36.7	78.9	2.15	3
Yorktown	6	2.94	116.1	39.5	32.4	105.4	3.25	6
Muncie.......								
TOTAL TRIP ..	62	3.12	98.4	31.5	37.8	92.1	2.44	44

K.W.H. per ton mile, 89.5 .... 67.0
K.W.H. per trips, 176.2 .... 128.0

An allowance of 45 passengers is made per trip, at an estimated weight of 3.00 tons.

TABLE XIV.

LIMITED RUN OF CAR No. 237.

Station.	EAST BOUND.				WEST BOUND.			
	Starts.	(A) K.W.H. Per Car Mile.	(B) Sq. Root Mean Sq. Cur.	Ratio B — A	Ratio C — D	(C) Sq. Root Mean Sq. Cur.	(D) K.W.H. Per Car Mile.	Starts.
Indianapolis . .	10	2.86	49.5	17.3	19.7	46.9	2.38	6
Siding 27.	2	2.19	78.2	35.7	25.1	44.2	1.76	1
Lawrence	0	1 66	37.8	22.8	25.9	31.6	1.22	
Oaklandon . . .	0	1.61	35.5	22.0				0
McCordsville. . .	1	1.34	41.0	30.6	18.4	45.7	2.48	1
Portville	0	1.89	40.8	21.6	21.5	38.3	1.78	1
Ingalls	0	1.41	38.4	27.2	20.4	44.0	2 16	0
Pendleton . . .	1	1.92	45.6	23.8	23.9	45.0	1.88	3
Anderson.	4	2.25	80.3	35.7	24.6	51.0	2.00	0
Chesterfield. . . .	0	1.92	45.9	23.9	20.7	41.1	1.90	0
Daleville.	1	1.87	48.3	25.8	23.9	41.9	1.75	1
Yorktown	1	2.23	50.5	22.6	2.23	53.5	2.40	3
Muncie.								
TOTAL TRIP. . .	20	2.02	46.0	23.6	22.8	44.4	1.95	16

K.W.H. per ton mile 69.8. . . . . 67.5
K.W.H. per trip. 114.2. . . . . .110.2

An allowance of 30 passengers is made per trip, at an estimated weight of 2.25 tons

TABLE XV.

LIMITED RUN OF CAR 252.

Station.	EAST BOUND.				WEST BOUND.			
	Starts.	(A) K.W.H. Per Car Mile.	(B) Sq. Rt. Mean Sq. Cur.	Ratio. B – A	Ratio. C – D	(C) Sq. Rt. Mean Sq. Cur	(D) K.W.H. Per Car Mile.	Starts.
Indianapolis	10	3.14	102.2	32.6	30.0	84.1	2.80	4
Siding 27.					39.7	72 6	1.83	2
Siding 15.	5	2.23	83.5	37.5	35:3	86.2	2.44	4
Anderson.	3	2.37	88.1	37.6	36.4	78.9	2.17	2
Muncie.								
TOTAL TRIP	18	2.32	87.2	37.6	36.2	78.0	2.10	12

K.W.H. per ton mile, 67.5. . . . . 60.3
K.W.H. per trip, 131.2. . . . . .118.8

An allowance of 30 passengers is made per trip, at an estimated weight of 2.25 tons.

TABLE XVI.

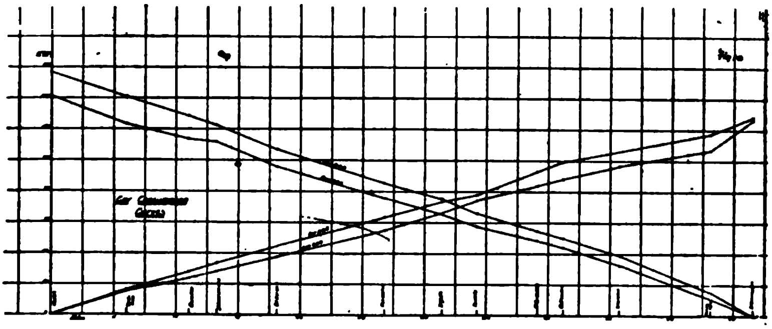
PERFORMANCE OF MOTORS ON CAR NO. 237 ON LOCAL TRIP FROM INDIANAPOLIS TO MUNCIE, MARCH 28, 1902.

	Time in Min.	Starts.	Dist. Miles	Ave. Speed M.P.H.	Max. Speed M.P.H.	K.W.H. Per Car Mile. A	Sq. rt Min. Sq Cur. (B.)	Ratio B — A	Max. Cur.	Min Volts on line
Indianapolis Siding 27	20	12	3.4	10	23	2.27	50	22	260	345
Siding 27 Lawrence	20	5	7.4	22	38	2.83	53	19	335	405
Lawrence Oaklandon	10	3	4.5	27	37	2.63	53	20	300	440
Oaklandon McCordsvil'e	5	1	2.1	25	37	2.12	47	22	255	430
McCordsvil'e Portville	8	2	4.8	26	42	1.91	43	23	265	415
Portville Ingalls	7	2	2.8	24	40	2.49	51	21	275	475
Ingalls Pendleton	12	3	4.7	23	42	3.39	49	21	320	390
Pendleton Anderson	23	5	8.7	23	39	2.29	49	21	370	380
Anderson Chesterfield	15	7	5.1	20	42	2.98	50	17	365	425
Chesterfield Daleville	5	1	2.0	24	36	1.50	36	24	255	525
Daleville Yorktown	8	1	5.1	38	43	1.90	41	22	325	475
Yorktown Muncie	19	8	6.0	19	41	2.84	49	17	320	425
Indianapolis Muncie	152	50	56.6	22	42	2.48	49	20	370	345

those for the east bound run. During this part of the trip conditions more nearly approximating the normal existed.

In Table XIV we have data bearing upon a complete round trip made by car 237 in limited service. The chief differences to be noted here by comparison with the data given in Table XII are that owing to the more uniform conditions of operation the ratios or running-factors are very uniform indeed, departing in general only to a slight degree from the total trip running-factors given at the bottom of the table.

Table XV. is a statement of the results obtained on a limited run upon car 252. Here it is seen that the ratios or running-factors are also comparatively constant, except where the car is operated within the limits of Indianapolis. Here the ratios are reduced somewhat; this is common in all similar urban runs.



For the purpose of presenting the data more clearly an expanded statement of it is made in Table XVI. for the western bound trip of car 237, mentioned in connection with Table XII. Here the time between points, starts between points, distance between points, average speed maintained between points, maximum speed between points, k.w.h. per car mile, running-factor, the square root of the mean square of the current, maximum current and minimum volts on the line between points, are recorded. On this trip car 237 attained to a maximum speed of 43 miles an hour running from Daleville to Yorktown. Between these two points but one start was made and an average speed of 38 m.p.h. was maintained. During this run therefore the maximum speed was but 13 per cent. in excess of the average speed. Again the data tells us that although the k.w.h. per car mile, 1.9, is low, still, since the minimum voltage on the line is high, and the maximum current, 325 amperes, moderate, the conditions in general

TABLE XVII

PERFORMANCE OF MOTORS ON CAR NO. 252 ON LOCAL TRIP FROM INDIANAPOLIS TO MUNCIE, MARCH 24, 1902.

	Time in Min.	Starts.	Dist Miles	Ave. Speed M.P.H.	Max. Speed M.P.H.	K.W.H. Per Car Mile. (A)	Sq. rt. Min. Sq. - Cur. (B)	Ratio B — A	Max. Cur.	Min. Volts on line.
Indianapolis.										
Siding 27	19	8	3.4	11	25	4.20	97	23	230	365
Lawrence	23	8	7.4	19	38	3.45	106	31	310	355
Oaklandon	12	5	4.5	23	40	3.32	107	32	280	350
McCordsville	5	2	2.1	25	36	2.63	98	37	250	320
Fortville	10	3	4.8	29	38	6.30	95	15	240	400
Ingalls	8	3	2.8	21	39	1.72	98	57	270	440
Pendleton	9	2	4.7	31	42	5.78	124	22	260	335
Anderson	32	14	8.7	16	38	5.17	109	21	370	300
Chesterfield	14	6	5.1	22	52	3.52	99	28	390	410
Daleville.	5	2	2.0	24	38	2.74	128	47	270	485
Yorktown.	11	3	5.1	28	43	2.82	74	26	270	360
Muncie	21	6	6.0	17	40	2.94	116	40	285	380
Indianapolis. Muncie	173	62	56.6	20	52	3.12	98	32	300	320

are favorable for an especially low square root of the mean square current. Accordingly, the running-factor has a high value, 22.

On the run from Anderson to Chesterfield on the other hand, the k.w.h. per car mile is 2.98 for a like distance of 5.1 miles, seven stops were made and a maximum speed was attained of 42 m.p.h. However, the average speed was only 20 m.p.h. or less than one-half of the maximum speed. These conditions, therefore, have a tendency to increase unduly the square root of the mean square current value, which is brought up to 50. In this case, then, owing to the fact that the maximum current is higher and the minimum current lower than in the first case cited, and furthermore, owing to the fact that during periods of starting a good deal of power is absorbed in the starting resistance, the k.w.h. per car mile increases faster than the square root of the mean square current value, and consequently we get a very low value, 17, for the running-factor. Where a good equipment is considered, the running-factor gives a fairly good idea of the conditions which obtain.

In this test the maximum value of the running-factor, 46, is 15 per cent. higher than the average value. The minimum value, 17, is 15 per cent. lower. Frequent stops, other things being equal, have the effect of lowering the running-factor. It is also true that the maximum current attained and the average minimum voltage under which the cars operate are important items in modifying it.

In Table XVII. results are given similar to those recorded in Table XVI. for a run between Indianapolis and Muncie of car 252 on local service. The number of stops made by car 250 on this trip is high and on arriving at Muncie it was 23 minutes overdue. The car consumption per car mile, 3.12 k.w.h., for this run is the highest obtained at any time during the tests and in itself shows the unfavorable conditions under which the car was operating. It was frequently required to lay over on sidings and in addition to make a great many intermediate stops. These unfavorable conditions are shown by the excessively high car consumption between McCordsville and Fortville, where a maximum consumption per car mile of 6.3 k.w.h. occurs. The average car consumption between these points, as shown by Table V., is but 2 k.w.h. per car mile. Again in running between Ingalls and Pendleton we have 5.8 k.w.h. per car mile, against an average value again of 2 k.w.h. per car mile in Table V. We also find that the average voltage at the motor terminals through

TABLE XVIII.

Variations in Line Voltage Between Stations During East and West Trips of Car No. 252.

Station.	Line Voltage Going East.			Line Voltage Going West.		
	Min	Ave.	Max.	Min.	Ave.	Max.
Indianapolis	365	456	590	335	418	460
Siding 27	355	446	585	310	442	580
Lawrence	350	475	580	350	453	540
Oaklandon	320		545	330	450	540
McCordsville	400	422	520	330	412	540
Fortville	440	483	575	385	482	535
Ingalls	335	477	580	410	450	535
Pendleton	300	406	550	300	408	540
Anderson	410	495	570	335	403	560
Chesterfield	485	523	545	515	540	560
Daleville	360	491	560	350	493	575
Yorktown	380	457	565	475	496	555
Muncie						

TABLE XIX.

Temperature Rise of Motors per Round Trip.

Number of Car.	Sq. Root Mean Sq. Current.	Temperature above Atmosphere, Degrees C.			
		Arm No. 1	Arm No. 2.	Field No. 1.	Field No. 2.
252	83	43.5	57.5	41.0	53.5
252	93	45.0	59.5	38.5	48.5
Average.	88	44.3	58.5	39.7	51.0
237	47	40.5	39.0	33.5	34.5
237	45	39.5	36.5	29.5	29.5
Average	46	40.0	37.7	31.5	32.0

that this run was quite low, the average minimum being 320 volts between Pendleton and Anderson.

It is not surprising therefore that the running-factor varies considerably in these tests. The value for the trip is 32, which is low for this car equipment; normally it runs as high as 37. The lowest value of the running-factor is 15 between McCordsville and Fortville. This is less than half of what it should be. The highest value is 57, between Fortville and Ingalls, which is 35 per cent, higher than it should be under normal working. The low value, 15 is due to the fact that the maximum speed is not much in excess of the average speed value, the maximum current values relatively low and both the minimum and average voltage values low, the former being 400 and the latter 422.

In the case of the run between Fortville and Ingalls, the maximum speed attained is nearly twice the average speed and the voltage is high; also the average voltage and the maximum current values are high. Low voltage invariably has the effect of decreasing the running-factor, whereas high voltage increases it. Notable examples may be taken for low values in the case of the run between McCordsville and Fortville and between Pendleton and Anderson. In these cases as shown in Table XVIII., the average voltage was respectively 422 volts and 406 volts. Examples of high values in the running-factor occur between Fortville and Ingalls, 57, and between Chesterfield and Daleville, 47. In these cases the average voltages were respectively 483 and 523.

It is not meant, however, that the voltage should be taken as the only criterion for variations in the running-factor. The number of starts, the maximum and average speeds and the current peaks also have much to do with it. In considering the records of the cars on these special tests it is not so much a matter of surprise that variations should occur in the running-factor as that under the variable conditions of actual service the running-factor should remain for the majority of the runs so nearly constant.

In Tables XIII. and XV. we see that during the east bound local run of car 252, although 44 stops were made, the running-factor does not vary materially from the running-factor given for the limited runs on this car both east-bound and west-bound. Of course during the limited tests the conditions which obtained were fairly uniform and therefore uniformity in the values of the running-factor should be expected. In the local runs this is not the case. However, Table XIII. shows that with variations in the k.w.h. per car mile of from 2.54 to 2.15 or through a variation of 18 per cent., the running-factor is practically the same.

A comparison of the values given in Tables XII. and XIV. show even better results than these. In these tables it will be found that numerous values of car consumption ranging from 1.61 k.w.h. per car mile to 3.27 k.w.h. per car mile can be picked out, giving a running-factor of 22. This is a variation in power consumption per car mile of over 100 per cent.

In making definite suggestions with reference to the ratio, which for want of a better term has been called a "*running-factor*," it is not meant to bring it forward as more than a means of getting some mental conception of what the conditions were which obtained during the special limited and local tests. When a large amount of data is accumulated, it is frequently a matter of some difficulty to arrange it so as to admit of intelligent comparisons being drawn between different sets of results, and anything which enables one to obtain a mental grasp of the situation is to be welcomed.

That the running-factor should in most cases be fairly constant under variable conditions of operation may be explained as follows. At times when a car is starting the $I^2 r$ losses in the windings are large, owing to the high starting current, and the core losses low, owing to the low speed. Therefore during the starting periods the $I^2 r$ losses dominate among the variable quantities in the measure of the total losses occurring in the motor. When a car has attained speed and uniform conditions of running have been reached, for instance on a level stretch of track, since the current values decrease, the $I^2 r$ losses fall to a normal value and the iron losses rise to a normal value at the same time. When operating under constant voltage the electrical energy delivered to the motors from the line is proportional to the current, but during the starting periods and when the high points of the $I^2 r$ losses are most important, the least amount of electrical energy supplied is being effectively utilized by the motors on account of the starting resistances and the fact that the motors are working at a point of low efficiency. Consequently, a temporary increase in the $I^2 r$ losses means also a temporary increase in the power supplied to the motors per unit of distance traversed, and we have, in a crude way, the variations in the power supplied per car mile following the variations in the heating value of the current.

Since the wattmeter connected in the field circuit gives the square root of the mean square of the current values and the wattmeter connected in the power circuit registers a value in excess of the average power delivered to the motors, it follows (curiously enough) that the ratios of the two wattmeter readings taken under widely different conditions, in different cases, are practically constant. This is an interesting fact if not a valuable one.

In comparing the running-factors of the two cars on the basis of k.w.h. per motor mile, instead of per car mile, it must be remembered that car number 252 is equipped with two motors which operate in parallel under normal conditions; whereas car number 237 is equipped with four motors operating in parallel under normal conditions. The running-factor values given in connection with car 237 are therefore only one fourth as large as they should be, and those given in connection with car number 252 only half as large as they should be for comparison on a k.w.h. per motor mile basis. That it is fair to assume an equal division of the current between the motors of the equipment of car 237 is shown by the curves shown in Fig. 9. The data for these curves were obtained during a special run to determine the division of current between the motors of this equipment. Although the division is not quite exact, yet it is sufficiently so for present purposes.

Following through the calculation, we find that the average running-factor per motor mile of the motors of the equipment of car 237 is 86.0 and the average running-factor of the motors of car 252, is 74.4. From this we would expect that for a given schedule the motors of car 237 will heat up more than will the motors of car 252 under the same conditions of service. This, however, is not the case, as is shown in Table XIX., which gives the temperature rise of the motors on both cars after single round trips between Muncie and Indianapolis.

From Table XIX. it is seen that the armatures of the equipment of car 252 run about 14° hotter than do the armatures of car 237 and that the fields of the motors of car 252 run about 15° hotter than do those of car 237. This difference is more than likely due to the fact that the smaller motors have greater radiating surface per unit of power developed. In fact, the common condition in motor design is that less trouble is experienced in supplying sufficient radiating surface for smaller motors than in supplying the proper radiating surface for large motors.

It is interesting to notice that of the motors on car 252, since No. 1 motor receives most of the breeze caused by the motion of the car, it being the one nearest the front, temperature of motor No. 1 is lower than of motor No. 2. In fact it has the advantage of motor No. 2 by about 12°.

In the matter of economic operation, car 252 shows a higher economy than does car 237. On the local trips car 237 consumed from 78 to 83 k.w.h. per ton mile, the starts per trip being 48 and 50 for the two runs respectively. Car 252 during its local trips showed a car consumption of 67 and 89 k.w.h. per ton mile, the starts being 44 and 62 per trip respectively. Comparing the trips, in which the number of starts are the same, car 252 shows up the best. In the limited trips the same result is apparent. As shown in Tables XIV. and XV., car 237 took an average of 68.6 k.w.h. per ton mile with an average of 18 stops for the two trips, whereas car 252 consumed an average of 63.9 k.w.h. per ton mile. The average number of stops of the latter car was 15.

The differences here brought out are not great, and a more extended test of the two cars would probably show that in general operation they have much the same power consumption.

In Fig. 10 curves are given to illustrate the rate of power consumption of cars 252 and 237 on local runs between Indianapolis and Muncie. No particulars that are especially worthy of note are developed by these curves except that car 252 shows a more uniform car consumption than does car 237, on both trips. When the cars were bound east, car 252 consumed the greatest amount of power whereas on the western trips car 237 shows a greater power consumption.

Inasmuch as the special tests made on cars 237 and 252 developed the fact that the limit of adhesion had not been approached in any of the tests, one of the equipments (car 255) of the type used on car 252 was furnished with a new set of gears making the gear ratio 23:48 instead of 20:50. The conditions under which car 255 was operated makes it difficult to compare its performance with that of either the limited or local runs made by the regular cars. The record of the tests of car number 255 discussed here was taken during a complete round trip. The instruments and observers were arranged in substantially the same manner as for the other special tests and the results of the test over the distance from Muncie to Anderson are plotted in Fig. 13. In Figs. 11 and 12 curves are given for local tests on cars 252 and 237 over the same distance. These curves make the relative per-

formance of the different cars apparent without undue explanation.

Under the ordinary conditions of local service starts are made about once in every one and one-half miles. In the test trip of car number 255, starts were only made at the principal towns along the route. In comparing therefore this test with the special tests of car number 252 we find that in local service car number 252 made less starts than did car number 255, and in limited service made more. A resumé of the performance of cars 255 and 252 is given in Table XX. From this table it is very evident that the change in the ratio of the gears produces a car capable of very much more efficient operation, in that its consumption per car mile is about the same as that of car number 252 whereas the speeds attained and maintained by the car are very much in excess of the local and limited service performance of car number 252. In this special run car number 255 maintained an average speed of 28 m.p.h. between the stations in Muncie and Indianapolis. Car number 252 maintained an average speed of 22 m.p.h. in the local service and an average speed of 27 m.p.h. in limited service between the stations in Muncie and Indianapolis. If the time during which the cars are passing through Muncie, Indianapolis and Anderson is deducted, we find that the average

TABLE XX.

COMPARISON OF CAR TESTS.

Number of car	255	252	252
Service, west bound	semi-limited	local	limited
Weight	63.100	63.100	63,100
Gear ratios	23.48	20·51	20 51
Total time trip, min	122	156	126
Time urban work, min	44	40	34
Time interurban work, min	78	116	92
Average speed for trip, m.p.h	28	22	27
Average urban speed, m p.h	8	9	10
Average interurban speed. m p h	30	26	33
Total starts	18	44	12
Urban starts	5	15	7
Interurban starts	13	29	5
Maximum speed, m.p.h	64	52	
Running speeds	50–55	40–45	40–45
Running currents	173	145	145
Train resistance corresponding lbs. per ton	27.7	19.9	19.9
Time to reach 25 m.p.h	30	30	30
Acceleration current. max. series	280–340	200–300	200–300
Acceleration current, max. par	320–540	250–300	250–300
Consumption, k.w.h., p.c.m., west	2.20	2.44	2.10
Consumption k.w.h., p.c.m., east	2.38	2.80	2 32
Sq. root mean sq. current, west	95–6	92.1	78.0
Sq. root mean sq. current, east	105.5	98.4	87.2
Running factors, west	43.5	37 8	36.2
Running factors, east	43.3	31.5	37.6
Average voltage, west	485	429	
Total consumption k.w.h., west	124.9	138.0	118.8
Total consumption k.w.h., east	134.3	176.2	131.2

speed maintained by car number 255 during the interurban run is 39 m.p.h., making 13 interurban starts. In the local interurban run of car number 252 an average speed of 26 m.p.h. was maintained, making 29 starts; and in the limited run of car number 252, an average speed of 33 m.p.h. was maintained with only five starts. Car number 255, therefore, excels the performance of car number 252, although car 252 was running under better schedule conditions in view of the less number of starts, made by it. In fact, in spite of the greater number of starts car number 255 made the interurban run outside of the cities in 78 minutes, whereas it took car number 252 in the limited service 92 minutes to make the run, and in local service 116 minutes to make the run. Since the square root of mean square of the current does not differ greatly from that shown by car number 252, the temperature of the motors working under the new conditions is not carried above a good allowable working value. The increased economy developed by this car is nothing short of remarkable, and it brings out very strongly the value that will accrue to any system in which careful adjustments are made of the car equipments to the work which they have to perform.

The earning capacity of the car in view of its ability to make the greater number of trips a day with the same crew is greatly increased by this change in the gearing and it is altogether a better machine as gauged by engineering and economic standards.

The running-factor of car number 255, figured on the car mile basis, is 48 for the west bound trip and 40 for the east bound trip. Calculated on the basis of the motor-mile basis, the average running-factor for car 255 is 86.8. Comparing this running-factor with those for cars 252 and 237, it is quite evident that the change in gearing has markedly influenced the running-factor of the motors raising it from 74.4 up to that of car 237; *i.e.*, 86.0. This is due to the fact that we have here a higher current consumption for a shorter time, thereby getting a higher square root of mean square value with approximately the same power consumption per motor mile, since under ordinary circumstances the voltage is approximately constant.

In comparing the train resistance of these cars, we find that when car number 255 is running at uniform speeds of from 50 to 59 m.p.h., showing an average of 55 m.p.h. at 554 volts and 143 amperes, the train resistance amounts to 27.9 pounds per ton. In the case of the tests of car number 252, the car maintained speeds of from 40 to 45 m.p.h., with a current consumption of about 145 amperes. This corresponds to a train resistance of about 19.9 pounds per ton.

The acceleration of the cars over this system does not differ very much from that common to steam roads. Cars 255 and 252 required from 30 to 31 seconds to attain a speed of 25 m.p.h. and very frequently a longer time than this was required, especially by car number 252. The rate of acceleration developed during the tests varied in general from about .4 to .9 m.p.h. per second. A maximum acceleration as high as 1.0 was attained occasionally on down grades, the minimum acceleration being about .25 m.p.h. per second.

The train records given in Figs. 12 and 13 are chiefly of interest in bringing out the fact that on this particular system low rates of acceleration exist largely through necessity. Where power is transmitted at 500 volts over considerable distances, an enormous expenditure in copper is necessary if high rates of acceleration are to be maintained at starting by cars remote from the substation. With the feeder distribution system of the Union Traction Company, a heavy current demand has the effect of so reducing the voltage at the cars as practically to limit the maximum obtainable rate of acceleration.

Comparing Fig. 13 with Figs. 11 and 12, the apparent ease with which car 255 attains to speeds running up close to 60 m.p.h. is quite remarkable. The average running speed of car number 252 being but little above 40 m.p.h.

APPENDIX.

It would be an unwarranted omission should this series of papers on the tests of the Union Traction Company, of Indiana, be closed without acknowledgement being made to the students of Purdue University who bore the burden and brunt of making the records during the three days of the general test.

In order to give these young engineers as varied experience as possible, a schedule was arranged whereby the men working in eight-hour shifts, eight hours on and eight hours off, would not have the same work to perform during any two working periods. Accordingly, a man who was on duty in the Anderson generating station during the first shift, might be in the Marion substation during the second shift, and, on an Indianapolis-Muncie division car during the third shift. The men were required to move from one station to the next during their relief time, and, also, to get their meals as well as sleep during this time. Frequently they had to sleep on cots in the substations, and, at times, on floors. Occasionally, owing to some disarrangement of the car service, a man was delayed in reaching his next post of duty and the observer whom he was to relieve had to work from 12 to 14 hours at a stretch. The men went through this trying ordeal without loosing records at any point and without a man having failed to report for duty at the scheduled time, except for causes beyond his control. The roll of the men who did this work and did it well, is as follows:

Seniors in Electrical Engineering Having Charge of Parts of the Tests.

J. P. DINSMORE,
J. F. DOSTAL,
W. B. GREGG,
F. B. HOFFT,
C. HOLLINGSWORTH,
R. A. PETICOLAS,
C. E. REID.
D. H. WILSON,
L. M. ZAPP,
O. C. STEIN,

Seniors in Electrical Engineering.

C. E. ADAMS,
E. D. FRISTOE,
B. M. MERRILL,
J. C. HUFFMAN,
N. F. ROBERTS,
F. B. WILKERSON,
A. E. WOOD,
J. W. DEITZ.

Seniors in Mechanical Engineering.

E. DAVIS,
T. W. NEWBURN,
J. S. TATMAN,
E. N. DASHIELL,
C. B. VEAL.

Seniors in Civil Engineering.

L. W. DINSMORE,
W. H. LANE.

Juniors in Electrical Engineering.

JUDSON BOUGHTON,
W. C. BRITTEN,
B. C. CONSTABLE,
I. B. CORNS,
C. O. DALE,
R. C. DIETZ,
I. HICKMAN,
J. B. HILL,
W. M. HOEN,
C. P. JOY,
F. W. JUDSON,
J. R. MCCONNELL,
J. K. OSTRANDER,
W. T. SMALL,
O. P. SMITH,
W. C. STARKEY,
D. R. WATERS,
H. WEAVER,
R. M. BRET,
F. S. DENEEN,
W. THORN.

Juniors in Mechanical Engineering.

T. M. ANDREW, A. R. KELLEY, R. E. CLISBY,
H. D. HARTLEY, J. H. PHLOEN,

Sophomores in Electrical Engineering.

R. W. HARRIS,
A. W. JOHNSON.

Sophomores in Mechanical Engineering.

I. E. ARTZ, A. F. BERGER, C. R. MISNER.

DISCUSSION OF "INTERURBAN CAR TESTS," COMMUNICATED BY E. P. ROBERTS AND I. H. SHERWOOD.

CAR TESTS ON NORTHERN TEXAS TRACTION COMPANY.

Numerous tests were made by Mr. Bret Harter of the interurban cars which were of three types, namely: (1) Standard interurban passenger car, (2) Larger and special parlor car, and (3) package frieght car, with and without trailer; and comparisons are given of the results obtained under different conditions of operation.

A description of the various cars and their equipment is as follows:

CAR.	No. 1 & No. 7.	SAGAMORE.	No. 12.	No. 9
Type	Standard closed Interurban Passenger.	Interurban Parlor Car.	Standard Interurban Express.	15-Bench Open Interurban Trailer.
Make	Kuhlman.	Kuhlman.	Kuhlman.	Kuhlman.
Length over all	44′ 5″	59′ 6″	40′ 0″	45′ 8″
Width	8′ 4″	8′ 5″	8′ 4″	8′ 0″
Total Weight in Tons, Car and Equipment	25.4	31.0	20	17.4
Number Motors	4	4		
Make	Westinghouse.	Westinghouse.	Westinghouse.	....
Mfg. No	56	76	56	
Gear Ratio	32–50	24–58	24–58	
Controllers	K 14	L 4	K 14	
No. of Trucks	2	2	2	2
Make	McGuire.	Brill.	McGuire.	McGuire
Mfg. No	35	27	35	40
Dia. of Wheels	33″	33″	33″	30″
Wheel Base	6′	6′	6′	4′ 3″
Make Brake	Christensen.	Christensen.	Christensen.	Christensen.
Type "	Direct Acting Storage Air.	Independent Direct Acting Air.	Independent Quick Acting Automatic Air.	Quick Acting Automatic Air

The dates of the test and weather conditions, etc., were as follows:

Date, 1902	9/16	9/17	9/17	8/19	9/22	9/24	11/14
Car	1	1	1	Sagamore.	12	12 and 9	7
Trip	1	1	1	1	1 and 2	1	1 and 2
Direction	E & W	E & W	E & W	E & W	E & W	E & W	E & W
Weather	Clear.	Cloudy (Rain Dallas end.)	Clear.	Clear.	Rain.	Clear.	Clear.
Temperature	90°	85°	85°	Warm.		Cool.	Cool.
Rail	Dry and clean.	Dry and clean except Dallas.	Dry and clean. Dallas end wet clean.	Dry and clean.	Wet and clean. Cities slippery.	Dry and clean.	Dry and clean.

In Ft. Worth, the interurban cars make a run of approximately 1.8 miles where high speed cannot be made; the terminus being at the court house.

In Dallas there is a distance of 4.1 miles of city track where slow speeds are required, and this is down grade, averaging possibly 1 per cent. Dallas is approximately 200 ft., lower than Ft. Worth.

DETAILED LOG OF RUN.

The following is an example of a portion of a log and is presented merely to indicate the general character of the observations made.

Time.	Place.	Track.	Position Controller.	Miles per hr.	Amp.	Volts.	Watt hr. Readings	Remarks.
12·32	26.5	S.S. 1	0		0	600	4299600	Coast to 24
37	24	0%	S		60	575		
	23.5		S	35	50	575		
38.5	23	0.14%+	S	26	70	570		
	22.3	1.3 %+	S	25	80	525		
41	22	0.17%+	S	28	60	535		
		0.15%+	S	28	50	500		
42.75	21	0.7 %+	S		50	485		
		0.7 %+	S		75	600		
	20.5	0.07%+	0		0	625		Coast to 20.1
44.5	G.P.	0.07%+	0	0	0	610	4305000	Stop
45	G.P.	0.07%+	S		80	530		
46	20	0.4 %+	S		80	530		
	19.9	1.0 %−	P					
	19.3	1.6 %+	P	40	175	450		
48	19	0.6 %−	0	0	0	630		Met a regular.
49	19		P		250			
50.5	18.5	0.2 %+	P	35	190	440		

See Tables I, II, III, IV.

Comparing Tables No. 1 and No. 2 it will be noted that the k.w. hours per car mile is greater for the entire run than for the high-speed portion only, and this is due to the greater number of stops in the towns and running on resistance. The average k.w. is less for the entire run than for the high-speed portion and this is due to the slower speed in towns, running on series.

The following illustrates this point:

T. & P. CROSSING TO OAK CLIFF, INTERURBAN RUN.

Car	No. 1*.	Sagamore.	No 12.	12 & 9	No. 7	No. 7.
Rate of run in m.p.h.	29.3	29.3	27.3	22.3	23.5	27.5
K.W. hrs. per mile	2.03	2.07	1.76	2.73	1.91	1.66
Watt-hrs. per ton mile	75.0	62.7	81.7	64.5	78.5	64.8
Average K.W.	59.4	61.	47.8	61.0	45.0	45.8

FT. WORTH TO DALLAS, ENTIRE RUN.

Car	No. 1†.	Sagamore	No. 12.	No. 12†	12 & 9	No. 7.	No. 7.
K.W. Hrs. per mile	2.16	2.15	1.88	1.81	2.81	1.94	1.76
Watt Hrs. per ton mile.	79 7	65.2	87.2	82.2	66.2	75.7	68.7
Average K.W.	48 1	52.7	37.7	42 1	56.4	35.6	36.5

* No. 1. Average of run of 9/17 Tables 1 and 2.

†12 – 12 & 9, Average of run. Ft. Worth to Siding 29

COMPARISON OF RESULTS OF TESTS OF CAR NO. 1.

Test of September 16th was with motors in parallel as much as possible, including hill climbing. Obtained high speed but more energy per car mile as compared with subsequent tests made September 17th, when the controller was handled more efficiently, and the car allowed to coast, though the speed was not quite as high.

CAR NO. 7.

Practically the same as No. 1.

The object of the two trips was to note a comparison of the effect of stops. The first trip having a considerable number and the second comparatively few, the result in k.w. per car mile is materially in favor of the second, especially on the west bound trips, where the time of the run is almost the same, but the stops almost three times as many. See Table I.

Also note Table II., which shows the effect of stops on the high speed run, where the result is very marked. Also note Tables III. and IV. Comparing No. 1 and No. 7 and the first test of September 17 of No. 1 and of November 14th of No. 7, there being about the same number of stops, shows that car No. 1 took more k.w. per car mile but the schedule speed was higher, whether the difference is entirely on this account we are not prepared to state, as there were many other circumstances which might affect the results, such as condition of the track, motorman, etc.

PRIVATE CAR " SAGAMORE."

It will be noted that the " Sagamore " makes practically the same schedule speed as the regular passenger cars, but it could not do this and make as many stops as the passenger cars are capable of making, for the reason that it is not geared for the same high running speed. Gearing for slower speed tends to efficiency of operation, but whether the materially better results obtained for the " Sagamore " in watt-hours per ton mile was entirely due to the gearing, is at least questionable. It will be noted that the k.w. hours per mile was about the same as for Car No. 1 for tests made on the 17th (and comparisons should not be made with tests made on the 16th because of special conditions of such tests). It should be noted, however, that car No. 7 gave better results in this respect than No. 1, and lower actual figures than the " Sagamore," but the watt-hours per ton mile were lower for the " Sagamore " than for No. 1, or even for No. 7, on test of same with the fewest number of stops.

CAR NO. 12.

Car No. 12 is a slightly lighter car than No. 1, and has the same motors as No. 1, and the same gearing as the "Sagamore." The k.w. hours per mile for the total run shown on Table I. was high, and with reference to Table IV., it will be noted that this was especially due to the run in Oak Cliff and Dallas. This car not only has frequent stops, but, owing to the character of the business, namely, taking up and discharging freight, it shifted back and forth at the sidings. etc., so that the results should not be compared on the same basis as obtained by other cars.

TABLE I

This gives the data obtained from the entire run of interurban cars. including runs in Ft Worth and Dallas.

Place	Ft. Worth to Dallas.														To Siding. No 20 to Dallas					
Date, 1902	9. 16	9/16	9/17	9. 17	9 17	9 17	9. 19	9 19	9/22	9. 22	9/24	9/24	9. 22	9. 22	9/24	9 24	11. 14	11 14	11/14	11. 14
Car	1	1	1	1	1	1	Sagamore		12	12	12 and 9		12	12	12 and 9		7	7	7	7
Direction	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W
Passengers	22	25	20	11	25	35	25	30												
Wt. of Pass. or Freight	1.6	1.9	1.5	0.8	1.9	2.6	1.9	2.2	0.5	2.5	5.0	5.2	0.5	2.5	5.0	5.2	0.3	0.3	0.3	0 3
Wt. of Car	25.4	25.4	25.4	25.4	25.4	25.4	31.0	31.0	20.0	20.0	37.4	37.4	20.0	20.0	37.4	37.4	25.4	25.4	25.4	25.4
Total wt.	27.0	27.3	26.9	26.2	27.3	28.0	32.9	33.2	20.5	22.5	42.4	42.6	20.5	22.5	42.4	42.6	25.7	25.7	25.7	25.7
Miles	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.5	35.1	34.4	34.6	30.5	30.4	30.4	30.3	34.5	34.35	34.35	34.35
Time	82.0	95.5	89.0	96.0	90.0	96.0	88.5	97.5	99.5	109.5	102.5	121.0	74.7	82 0	88.5	93 0	113.5	113.5	91.85	108.5
Miles per hr	25 1	21.6	23.1	21.4	22.8	21.4	23.2	21.2	20.8	19.2	20.1	17.1	24.4	22.2	20.6	19.6	18.2	18.1	22.4	19.0
K.W hrs.	84.6	86.4	70.2	73.2	75.6	77.4	72.0	75.6	58.2	72.6	88.8	98.4	52.4	57.6	82.2	88.8	64.2	69.6	59.1	62.1
K.W. hrs. per mile	2.46	2.52	2.04	2.13	2.2	2.26	2.1	2.2	1.69	2.07	2.58	2.84	1.72	1 9	2.7	2.93	1.86	2.03	1.72	1 81
Watt. hrs. per ton mile	91.0	92.5	76.0	81.5	80.5	80.6	64.0	66.5	82.5	92.0	61.0	66.5	80 0	84.5	63.5	69.0	72.5	78.9	67.0	70 4
Average K.W	61.8	54.3	47.3	45.8	50.4	48.4	58.8	46.6	35.5	39.9	52.0	48.8	42 0	42.2	55 6	57.3	33.9	36.7	38.6	34.4
Stops			25	27			24	24	19	14	15*	13*	13	9	8	8	29	30	15	11

*No 9 Trailer dropped and picked up at Siding 29, Oak Cliff, City Limits.

TABLE II.

This gives the resuts obtained on the high-speed portion of the road, being strictly the interurban section.

Place	T. & P. Crossing to Oak Cliff City Limits.															
Date	9/16	9/16	9/17	9/17	9/17	9/17	9/19	9/19	9/22	9/22	9/24	9/24	11/14	11/14	11/14	11/14
Car	1	1	1	1	1	1	Sagamore		12	12	12 and 9		7	7	7	7
Direction	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W
Passengers	22	25	20	11	25	35	25	30								
Wt. Pass or Freight	1.6	1.9	1.5	0.8	1.9	2.6	1.9	2.2	0.5	2.5	5.0	5.2	0.3	0.3	0.3	0.3
Wt. of car	25.4	25.4	25.4	25.4	25.4	25.4	31.0	31.0	20.0	20.0	37.4	37.4	25.4	25.4	25.4	25.4
Total wt. in tons	27.0	27.3	26.9	26.2	27.3	28.0	32.9	33.2	20.5	22.5	42.4	42.6	25.7	25.7	25.7	25.7
Miles	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.6	28.5	28.6	28.5	28.6	28.45	28.45	28.45
Time	53.2	58.5	59.5	57.5	58.5	57.25	56.5	60.0	62.25	63.5	72.75	81.0	72.75	73.0	59.5	65.0
Miles per hr	32.0	29.1	28.6	29.6	29.1	29.8	30.2	28.4	27.6	26.9	23.6	21.1	23.6	23.4	28.7	26.3
K.W. hrs	72.0		57.6	54.0	61.8	57.0	61.2	57.0	49.2	51.0	76.2	79.8	55.8	53.4	48.3	46.5
K W. hrs. per mile	2.54		2.03	1.9	2.18	2.01	2.15	2.0	1.74	1.79	2.66	2.80	1.95	1.87	1.70	1.63
Watt hrs. per ton mile	94.0		75.5	72.5	80.0	72.0	65.5	60.0	84.0	79.5	63.0	66.0	78.9	78.0	66.1	63.6
Av. K.W.	81.3		58.1	56.4	63.4	59.7	65.0	57.0	47.4	48.2	63.0	59.1	46.1	43.8	48.7	42.9
Stops			9	8			9	9	7	5	5	5	21	21	4	6

TABLE III.

This gives the results obtained in Ft. Worth.

Place	Ft. Worth Terminal to T. & P. Crossing.															
Date	9/16	9/16	9/17	9/17	9/17	9/17	9/19	9/19	9/22	9/22	9/24	9/24	11/14	11/14	11/14	11/14
Car	1	1	1	1	1	1	Sagamore		12	12	12 and 9		7	7	7	7
Direction	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W
Passengers	22	25	20	11	25	35	25	30								
Wt Pass. or Freight	1.6	1.9	1.5	0.8	1.9	2.6	1.9	2.2	0.5	2.5	5.0	5.2	0.3	0.3	0.3	0.3
Wt of car	25.4	25.4	25.4	25.4	25.4	25.4	31.0	31.0	20.0	20.0	37.4	37.4	25.4	25.4	25.4	25.4
Total wt. in tons	27.0	27.3	26.9	26.2	27.3	28.0	32.9	33.2	20.5	22.5	42.4	42.6	25.7	25.7	25.7	25.7
Miles	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Time	13.3	11.5	13.0	14.5	15.0	14.25	16.5	13.5	12.5	18.5	15.75	12.0	12.75	17.0	14.25	12.5
Miles per hr.	8.1	9.4	8.3	7.45	7.2	7.6	6.55	8.0	8.64	5.8	6.9	9.0	8.47	6.35	7.58	8.66
K W. hrs.	7.2		6.6	9.0	7.2	9.6	6.8	9.0	3.6	6.6	6.0	9.0	3.9	6.3	4.8	6.3
K.W. hrs. per mile.	4.0		3.66	5.0	4.0	5.34	3.78	5.0	2.0	3.66	3.33	5.0	2.16	3.5	2.66	3.5
Watt hrs per ton mile	148.0		136.0	191.0	146.0	190.0	115.0	150.0	97.5	162.0	78.5	117.0	84.3	136.0	104.0	136.0
Av. K. W.	32.4		30.4	37.2	28.8	40.4	24.7	40.0	17.3	21.4	22.8	45.0	18.3	22.2	20.2	30.3
Stops			10	14			10	10	6	4	3	3	4	3	5	1

TABLE IV.

This gives the results obtained in Oak Cliff and Dallas.

Place	Oak Cliff City Limits to Dallas Terminal.															
Date	9/16	9/16	9/17	9/17	9/17	9/17	9/19	9/19	9 22	9 22	9 24	9 24	9 14	9/14	9/14	9/14
Car	1	1	1	1	1	1	Sagamore		12	12	12 and 9		7	7	7	7
Direction	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W
Passengers	22	25	20	11	25	35	25	30								
Wt. of Pass. or Freight	1.6	1.9	1.5	0.8	1.9	2.6	1.9	2.2	0.5	2.5	5.0	5.2	0.3	0.3	0.3	0.3
Wt. of car	25.4	25.4	25.4	25.4	25.4	25.4	31.0	31.0	20.0	20.0	37.4	37.4	25.4	25.4	25.4	25.4
Total wt. in tons	27.0	27.3	26.9	26.2	27.3	28.0	32.9	33.2	20.5	22.5	42.4	42.6	25.7	25.7	25.7	25.7
Miles	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.8	4.0	4.3	4.1	4.1	4.1	4.1
Time	15.5	25.5	16.5	24.0	16.5	24.5	15.5	24.0	14.75	27.5	14.0	28.0	18.0	23.5	18.1	31.0
Miles per hr.	15.9	9.65	14.9	10.2	14.9	10.0	15.9	10.2	16.7	10.5	17.1	9.2	13.6	10.5	13.6	7.94
K.W. hrs.	5.4	10.8	6.0	10.2	6.6	10.8	4.2	9.6	5.4	15.0	6.4	9.6	4.5	9.9	6.0	9.3
K.W hrs. per mile	1.31	2.64	1.46	2.49	1.49	2.64	1.02	2.34	1.32	3.13	1.6	2.23	1.1	2.42	1.46	2.27
Watt hrs. per ton mile	48.5	97.0	54.5	95.0	44.5	94.5	31.0	71.0	64.0	130.0	37.8	52.5	42.7	94.0	57.0	88.3
Av. K.W.	20.9	25.4	21.8	25.5	22.2	26.4	16.2	24.0	22.0	32.8	27.4	20.0	15.0	25.3	19.9	18.0
Stops			6	5			5	5	6	5	7	5	4	6	6	4

NOTE:—It should be noted that the results in Table No. 4 are included in those given in Table No. 1. and also that, at the time of the tests, the Oak Cliff Line was in poor condition as to track, bonding and overhead work. This was an old line, which has since been rebuilt.

The effect of adding a trailer on the k.w. hours per mile and the watt hours per ton mile is very marked, both on the entire run as given by Table I. and for the portions of the run as given by Tables II., III. and IV. the reduction in watt-hours per ton-mile being very considerable.

In connection with the above it should be noted that the average k.w. for the entire run (see Table I.) for the regular passenger cars is less than 50 k.w. (omit test of September 16th, which was intentionally made under uneconomical conditions). Therefore, if the average efficiency of the motors was 75 per cent., the average output of the motors was slightly less than one-quarter of their rating and it should also be noted that this does not include time for lay-over, which gives opportunity for cooling. Each motor is rated at 55 h.p.

[COMMUNICATED AFTER ADJOURNMENT BY MR. A. H. ARMSTRONG]

In commenting upon the very admirable paper brought out by Messrs. Goldsborough and Fansler, one point strikes me as rather inconsistent, and that is the elaborate methods taken to secure and make use of the square root of the mean square current per motor. As the chief object of the tests seemed to be to obtain this value, it is interesting to note what use is made of it. To this end Mr. Goldsborough has constructed a new term which he calls the " running-factor," this being the ratio of the square root of the mean square current per motor to the kilowatt hours per car mile. The term has no rational reason for existence, as obviously this " running-factor " or ratio will vary widely, depending upon the kind of service and will in no way serve as an indication of whether the proper motors are used, whether the gearing is correct, etc. It is obvious that the kilowatt hour per car mile depends largely upon the gear ratio used, and the rate of acceleration chosen for a given schedule and frequency of stops. With the series-parallel controller, a service calling for much series running will considerably affect the kilowatt hours per car mile without in any way affecting the square root of the mean square current. For long runs there may be some similarity in the values obtained for this " running factor," but the results cannot be used in any comparative sense, have no direct bearing upon the fitness of the equipment for the work, and not in any way indicate the heating of the motors. The term seems to me to complicate an otherwise rather simple problem without in any way furnishing additional accuracy. The use of the "running-factor " term ignores the possible efficiency of acceleration of the motors. This efficiency of acceleration is the ratio of work done by the motors to the energy input of the car or train, and will vary from 40 per cent. to as high as 75 per cent. or 80 per cent. on the longer runs. The square root of the mean square current is not at all affected by the efficiency of acceleration of the motors, and hence any conclusions drawn from the ratio of square root of the mean square current to the kilowatts per car mile input must necessarily show considerable variation, due to the variable efficiency of acceleration of different lengths of runs.

Mr. Goldsborough noted a considerable variation in energy consumption on the shorter runs. I believe this was largely due to the fact that the method of taking ampere time curves was not well adapted to very short runs when the accelerating current forms the greater part of the total ampere input. Some time ago at Schenectady we were met with this same difficulty and some of our engineers advised a recording voltmeter and ammeter which gave the current reading at every instant, thus eliminating the personal element of the observer and giving much more accurate results than can be obtained with either two second or five second readings.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 30, 1903.

SOME RECOMMENDATIONS CONCERNING ELECTRICAL AND MECHANICAL SPECIFICATIONS OF TROLLEY INSULATORS.

BY SAMUEL SHELDON AND JOHN D. KEILEY.

INTRODUCTION.

At present there appears to be no standard basis for comparison of the relative merits of insulators which are supplied for use in ordinary overhead trolley line construction. It is obviously desirable that there should be a definite basis upon which a proper selection can be made.

With a view to formulating specifications of such materials, it was found necessary, on account of the lack of published data on the subject, to conduct a series of tests to determine the electrical and mechanical properties of these materials. The tests were made upon samples obtained in the open market from the stocks of well-known manufacturers. Some of the results of these tests are given below and recommendations concerning specifications of certain types are appended.

Determinations were made of the tensile strength of the samples, of the voltage necessary to perforate the insulation or produce an arc between conducting parts, of the mechanical softening temperature, and of the relative magnitudes of the insulation resistances.

TENSILE STRENGTH.

These tests were made in the usual manner; the samples being pulled apart by means of a Riehle 30,000 lb. universal machine. U-shaped pieces of round steel were passed through the metal eyes of such samples as globe, Brooklyn strain, and terminal strain insulators, and were clamped in the jaws of the machine.

The insulated bolts were passed through a properly sized hole in a steel plate. The threaded end was connected with a steel eyebolt by means of a steel threaded sleeve, and the tension was exerted between the eyebolt and the plate. The results obtained from breaking the samples are given below, the product of different manufacturers being represented by the letters *A* *B*. *C* and *D*. The numerals represent the tension in pounds at the time of break.

2½″ Globes.

A	*B*	*C*	*D*
3710	5950	7725	6320
4510	5770	7475	6890

3″ Globes.

A	*B*	*C*
4210	11190	5450
5310	8930	5550

Small Brooklyns.

A	*C*	*D*
9990	10320	5520
11130	9010	6450

Large Brooklyns.

A	*B*	*C*
11490	19670	18510
10510	17140	18250

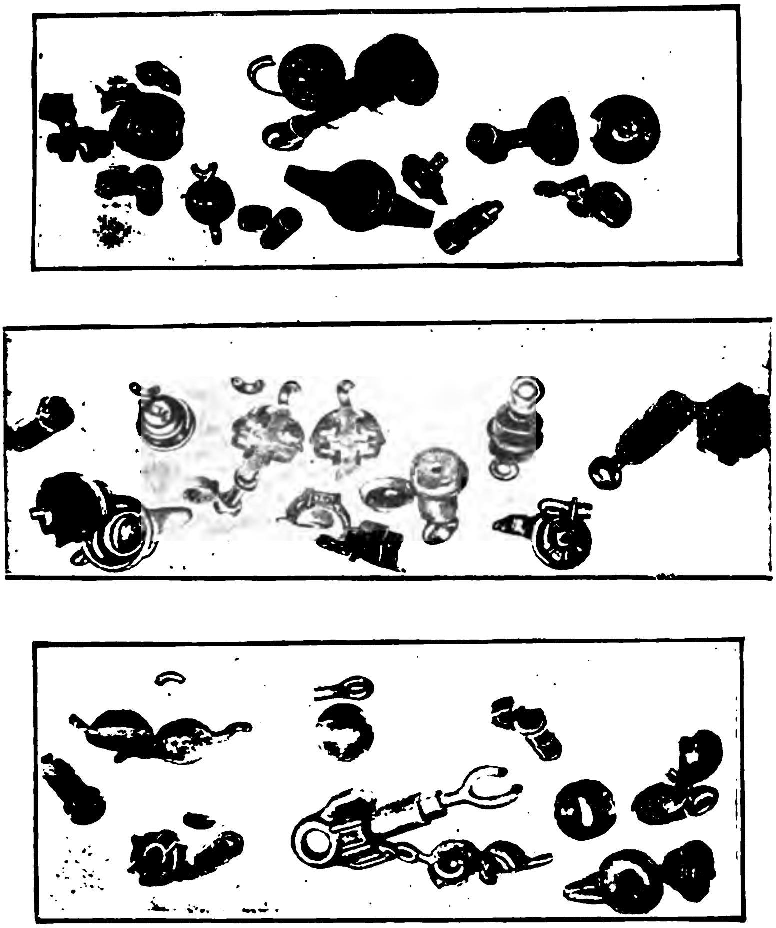
Insulated Bolts.

A	*B*	*C*	*D*
6370	6130	7360	3280
4495	5490	9010	2925

Some of the broken samples are shown in the accompanying illustrations. It will be noted that while some samples gave way in the eyes, others broke in the insulation. It is very desirable that strain insulators should be so designed that when subjected to a test for tensile strength, they should give way in the eyes. As these insulators are subjected to an uncertain strain while being installed and after being in use, it is of great importance that one may be able to depend upon the fact that, if the eyes be intact, the insulation is also in good condition.

BREAKDOWN VOLTAGE.

In carrying out these tests, the two metal portions or conductors of the insulators were connected respectively with the two high-pressure terminals of a 1:200 step-up transformer, whose low-pressure terminals were connected in series with a regulating rheostat to a supply of alternating current at a frequency of 60. A dead-beat voltmeter was connected to the low pressure terminals. By manipulating the rheostat any desired voltage could be impressed upon the low-pressure coil and its value could be determined from the voltmeter. The high-pressure voltage would be 200 times as large, provided the



FIGS. 1, 2 and 3.

secondary was unloaded; that is, provided the insulator were unpunctured and there were no arcing present. The test was started with a low impressed voltage which was gradually raised until a sudden drop in the voltmeter reading indicated that a breakdown had occurred. The maximum reading multiplied by 200 is the breakdown voltage. The following results were obtained.

2½″ Globes.

A	*B*	*C*	*D*
8010	8610	5610	7500
	7610	5110	6110
		4510*	5910

3″ Globes.

A	*B*	*C*
11410	12810	8010
10810	10810	9010

Small Brooklyns.

B	*C*	*D*
14810	6710	35000
	5510*	

Large Brooklyns.

A	*B*	*C*
8010	14410	11410
4210	13010*	7610*
4010*		

Insulated Bolts.

A	*B*	*C*	*D*
12010	14450	12210	arc at
13010	14450	10010	25000

The voltage necessary to rupture the dielectric would undoubtedly have been less than the amounts given above if the duration of the application of the high pressure had been increased. In practice, trolley insulators are seldom subjected to a voltage greater than that of the generators or converters. Occasionally, however, they are subjected to moderately high voltages of short duration which arise from the disappearance of magnetic flux that has been created by short circuits. The values given above which are followed by an asterisk were obtained from tests on insulators which were, at the time, under a tensile strain of about 4500 lbs. The dielectric strength is slightly reduced by strain, but in all the samples tested it was sufficiently high to meet the requirements of present practice

HEAT TESTS.

Oftentimes when a trolley wire breaks it becomes heated on account of the grounding of a broken end. Sometimes the insulating material in the round-top hangers softens under the influence of the heat communicated from the wire and allows the ear and suspended wire to drop to the ground. Efforts were made to determine the temperature of the insulation at the time of softening. A hanger was screwed into a regular ear, and was suspended in an inverted position in a double-walled oven. A wire was attached to the suspended cap and was passed through a hole in the bottom of the oven. To this wire was attached a weight of 100 lbs. This weight is equal to that of about 200 feet of No. 000 copper trolley wire and it is quite possible that a hanger might be subjected to this strain. The temperature of the oven was raised by means of burning an arc lamp which was enclosed in it. As the temperature rose to a certain point, the insulating material softened and the suspended weight pulled the round top cap of the hanger away from its bolt. This temperature was noted on a mercury thermometer whose bulb was placed near the ear. Unquestionably, the temperature varies very much at different points inside the insulating material, such material being a good heat insulator as well as an electrical insulator. The material next to the metal, however, is probably the hottest and the temperature is nearly that of the metal. It is at this point that it softens most. The results obtained from three samples were, *A* 168° C.; *B* 168° C.; and *C* 145° C.

Appreciating the uncertainty of such a test, another method was devised which tested the hangers under working conditions. This method gives but relative results. Under the circumstances they are more to be desired than absolute values of temperature.

A soft iron round rod, ¼″ in diameter and 20″ long was clamped by an ordinary trolley ear, whose ends had been cut off so as to leave a length of 5½″. This was suspended (Fig. 4), by means of a wire stirrup underneath a beam. Into the ear was screwed the bolt of the round-top hanger to be tested. To the cap of the hanger was suspended a weight of 200 pounds. A current of 200 amperes was then sent through the iron. The time which elapsed between closing the circuit and the separation of the parts of the hanger under the influence of the weight was noted.

These times in minutes were as follows:

A	*B*	*C*	*D*
50	34	94	74

Two similar samples from the same manufacturer were tested, one with the cap underneath, as above described, and the other with the ear beneath. The times between the closing of the circuit and the breaking down of the insulators were respectively 31 and 33 minutes. This indicates that the position in regard to vertical arrangement during test is immaterial.

Efforts were made to determine roughly the character and the composition of the insulating materials employed by each manufacturer. Upon ignition, by applying a lighted match, each of the insulating materials burned quietly with a very small flame. There was some smoke and in all cases the characteristic odor of burning shellac. Each sample when placed in alcohol went partially into solution, leaving a residue. Mica and asbestos were present in some of the residues.

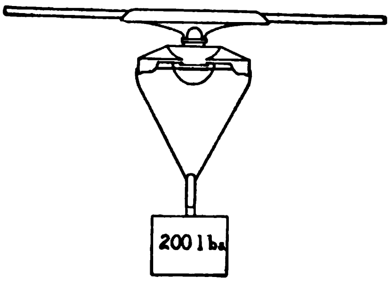


FIG. 4.

If the binding material be, in all cases, shellac, it is evident that the softening temperature is an indeterminate quantity. Shellac is somewhat viscous at ordinary temperatures, and its viscosity rises rapidly with increase of temperature. Insulating bolts, one from each manufacturer, were placed in boiling water and were allowed to remain until they had assumed the temperature of the water, *i.e.*, 100° C. In each case the insulating material had softened so as to permit of moulding under slight pressure. The viscosity, at a given temperature, is also dependent upon the relative amount of shellac to the other material present. This amount is liable to variation in samples of the same type from the same manufacturer.

INSULATION RESISTANCE.

The resistance of an ordinary strain insulator is very large, and, if it were not for the large number of them which are connected in parallel on a trolley system, no consideration need be given to this point. It is difficult to determine rapidly the individual resistances in ohms, hence the following method of determining the relative resistance values was devised.

A Holz machine when run at a constant speed, owing to its practically infinite internal resistance, functionates as a constant current generator. For obtaining the comparative values of the resistances of the insulators, such a machine was used as a source of e.m.f., and an arrangement of apparatus as shown below was employed:

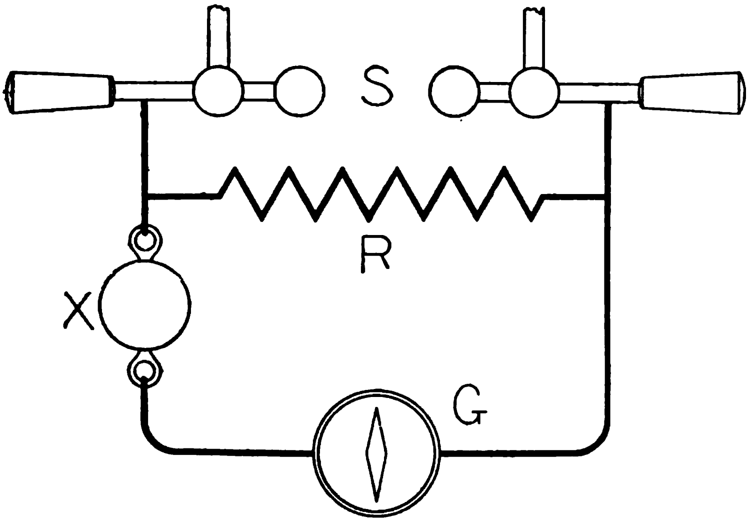


FIG. 5.

where S = spark gap of the Holz machine;
X = insulator under test;
G = a mirror galvanometer;
R = a resistance in which is included the leakage resistance of the Holz machine, and of the connecting wires.

By connecting together the two terminals of the insulator X, by means of a copper wire, practically all of the current I, which is produced by the machine, is made to pass through the galvanometer and it produces a deflection θ Upon removing the copper wire, a current i_x will flow through the galvanometer, giving a deflection θ_x.

This deflection will be inversely proportional to the resistance of X. The rest of the constant current I will pass through R, which includes the leakage paths. Representing this current by i_R, there exists the following relations:

$$I = i + i_R$$

$$I - i_x = i_R$$

$$i_R\, R = i_x\, X = (I - i_x)\, R$$

$$\therefore X = \frac{I - i_x}{i_x} R$$

Since I and i_x are proportional to deflections θ and θ_x respectively.

$$X = \frac{\theta - \theta_x}{\theta_x} R$$

By substituting for X another insulator, its resistance can be quickly determined in terms of R in a similar manner. This method is better suited for getting the comparative resistances of insulators of the same shape, than for getting their absolute resistances. A portion of an insulator's conductance unquestionably consists of surface leakage.

The resistances obtained are given below in terms of an arbitrary standard:

2″ GLOBES.

A	B	C
61	98	1.7
55	76	12.0

2½″ GLOBES.

A	B	C
27	36	1
55	18	1.5
61	37	1

SMALL BROOKLYNS.

B	C
35	40
35	43

LARGE BROOKLYNS.

A	B	C
0.7	39	27
0.8	41	27

SPECIFICATIONS.

Specifications for the various forms of insulators used in trolley construction must vary with local conditions and with the policy of the user. Specifications for Globe and Brooklyn Strain insulators should cover the following points:

1. Dimensions.
2. Size of eye.
3. All samples tested shall break in the eye.
4. The average ultimate tensile strength of all samples subjected to mechanical test shall not be less than A lbs., and no individual sample shall show a tensile strength of less than 85 per cent. of the average tensile strength of all the samples that are tested.
5. The average breakdown voltage, for samples which have been broken in the eye in the mechanical test, shall not be less than B volts, and no individual sample shall break down at less than 90 per cent. of B volts.

As to the values to be specified for ultimate tensile strength and breakdown voltage, the following are suggested, where high class insulators for use on 500 volt lines are to be specified.

	Ultimate Tensile Strength in lbs.	Breakdown Voltage.
2½ inch globes	6000	7000
3 " "	9000	10000
Small Brooklyns ...	9000	10000
Large " ..	18000	10000

Owing to the comparatively low softening temperature of the insulating materials generally used, and to the close proximity of the working conductor when in service, it is important that specifications for round-top hangers should impose a test for softening temperature. The following " hot rod test " is suggested:

Round-top hangers when suspended free from draught in an inverted position by means of a bronze ear weighing 8 ounces and being 5½ inches long, the ear clamping the middle of a round rod of soft iron ½ inch in diameter and of at least 20 inches length between connectors, must be able, without breaking down or becoming permanently deformed by more than 1/16 inch, to sustain a weight of 200 pounds from the cap for one hour, a current of 200 amperes being passed continuously through the iron rod, the rod being cold at the start.

DISCUSSION.

MR. JOSEPH SACHS:—Moulded street railway insulators of the type that Dr. Sheldon describes are usually made of some loose inert insulating material mixed with a binding gum and compressed into shape. In many cases the formula would appear to pay little, if any, attention to the essential electrical characteristics of the ingredients, so long as the minimum gum and the maximum filler that would hold together were used. I most heartily second the recommendation Dr. Sheldon has made to standardize street railway insulator specifications. So far as some of his proposed requirements are concerned, however, I want to differ somewhat from him. In the first place, we may agree so far as the breaking of strain insulators is concerned in the elements exterior to the insulator. The mechanical strength of a strain insulator should be indicated by some exterior element. But there are other features to be considered mechanically, aside from the mere pulling. One of them is the knocking and vibration to which an insulator is subjected in regular service. Another and a very important factor in all insulators, is their stay-togetherness. I may say that nearly all moulded insulators to-day are bound together with shellac, or some gum or similar substitute. The insulating material in these insulators when softened under heat will permit the two strain parts, or the electrodes, we might say, of the insulator to pull apart, unless some mechanical provision, aside from the moulded insulation, is provided for holding them together. I believe that should be considered as an important element. In fact, all strain insulators or all trolley line insulators should be so constructed that under service strain conditions, if the moulded insulation should be ruptured, the two parts are still held by a mechanically stronger insulation.

I believe that the table for mechanical pulling strength on the ninth page is entirely too high. I can scarcely conceive of 18,000 pounds as being a necessary tensile strength for even a large Brooklyn strain insulator, although there may be special conditions where such may be the case. I know of very few strain insulators that stand in actual continuous service, with the rapping and knocking, even as much as eight or nine thousand pounds. These latter figures for first-class strain insulators of usual size should prove ample.

Now, again, the matter of melting point; the melting point of the moulded insulation used in nearly all trolley line insulators can be increased at the expense of its insulating properties. Such results can be obtained by using ingredients that give the compound a larger specific heat. These materials are mostly of a metallic oxide nature, and the insulation resistance and dielectric strength is usually brought down accordingly.

The iron bar heat test method described by the writers of the paper is good, but I believe it is carried a little too far. I think there are few practical conditions where enough heat would be generated in a trolley wire, and then only in case of a dead short circuit from the trolley wire to the ground, which probably in many instances, or in most instances, would open up something on the line.

The puncture-resisting strength of the insulator is, I believe, quite important, but I think too much stress is laid on the question of dielectric strength. An insulator for trolley use is mostly subjected to leakage conditions. On 500 volts it takes very little internal insulation to make the insulator stand up, but it takes a whole lot of surface and a whole lot of good material well put together to keep the insulator intact on the outside. not on the inside. Trolley-line insulators are subjected to heating and cooling. The surface gets sticky and moist, accumulating dirt, and in a very short time of good, hard service we find more trouble arising from leakage conditions, due to cracks and other similar causes, surface leakage, and so on, than due to any actual puncturing of the interior; even though you might get inductive kicks due to short circuit suddenly being taken off the line.

I cannot see why, for trolley service of the same voltage, all insulators should not be subject to the same specifications so far as breakdown voltage is concerned. I do not see why a small insulator should be subjected to only 10,000-volt breakdown test, while a large insulator should have to stand more. Again, I find that the difficulty with most trolley-line insulators isthat long before the breakdown point occurs the voltage will jump across the surface. We have found this difficulty to a great extent, not when the insulator is in its ideal condition; that is, perfectly dry and quiet and nice in the factory, but when you get it outside and expose it to the weather for quite a while.

As I have said, the matter of resistance of the insulators is governed greatly by the ingredients used. Almost any kind of insulation when dry will show high resistance. It takes but very little good shellac and good mica, or similar material of good quality, well bound together by binding material, to give you a pretty good high insulation resistance, dry and perfectly handled; but put it out on the line, let the thing crack, let a little moisture creep in, and that is the time when you want to get your insulation resistance. Insulators which look on the laboratory instrument absolutely perfect, when subjected to even a short period of service soon show very low insulation resistance. In considering standard specifications for trolley insulators, therefore, I want to suggest the following:

Continued-service insulation cannot be determined by dry insulation tests.

Internal dielectric strength is more readily obtained than a satisfactory surface insulation.

A low temperature strain test is of little value to obtain the service-strain resistance of a moulded strain insulator.

Strain insulators should hold together and insulate under strain and with moulded insulation removed.

MR. RALPH D. MERSHON:—Just one point in regard to this paper. I notice the tests were made with alternating current. It seems to me the insulators would have shown up better if the tests had been made with direct current, as insulators of this type, made with shellac, soften to a greater or less extent with alternating current. I made a test some time ago of the material used in such insulators, and found this softening effect in a marked degree. We tested in order to get a general idea as to the difference in the behavior of the insulators with alternating and direct current of the same voltage. The heating was much more marked with the alternating current. With it the insulator softened and broke down after a time, whereas on the direct current it was apparently good for an indefinite period.

MR. SACHS:—May I ask what the voltage was at which you tested the insulators, and the frequency?

MR. MERSHON:—They were tested at a number of voltages, and my recollection is that the frequency was 60 cycles. We tested them at 500 volts, direct current and 500 volts alternating current, noting the difference in the effect in the two cases. The insulators heated up very considerably on the alternating current, whereas they showed no signs of heating on the direct current?

MR. SACHS:—What was the duration of the test?

MR. MERSHON:—As I recollect, it was several minutes before you could feel that the insulator was getting warm with the alternating current.

DR. SHELDON:—I think that the breakdown test is properly made with the alternating current, because when the insulator is subjected to the inductive kick which has been spoken of, the effect is much more like that due to an alternating current than that due to a direct current; as regards the measurement of these resistances by this method, the surface leakage is taken into account.

MR. MERSHON:—It seems to me that the breakdown test with alternating voltage is not the proper one, for the reason that an element comes in of which I think Dr Sheldon has not taken account—the hysteretic loss, which heats and softens the insulation, thus causing it to break down where with the same direct current electrical stress it would not break down. That is to say, you might put on a direct current which would have the same value of kick that Dr. Sheldon speaks of and not break down the insulator at all, whereas if you put on an alternating current of considerably less maximum voltage, it might break down, depending on the frequency and how long you kept the voltage on.

MR. SACHS:—I have recently made a series of tests on some insulations at high potentials in oil baths. I found, in every case where the potential had remained on the insulating piece for quite a while and then punctured, indications of softening right close to the electrodes. So that certainly would bear out what Mr. Mershon says regarding the heat effects.

A paper read at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 30, 1903.

THE STORAGE-BATTERY IN SUBSTATIONS.

BY W. E. GOLDSBOROUGH AND P. E. FANSLER.

The rapid development of interurban electric traction has brought with it a new field for the economic utilization of the storage-battery. Inasmuch as in interurban electric traction it is the practice to develop the energy for the operation of any one system in one or two large generating stations and to distribute this energy to the trains through the medium of substations, in these substations the storage-battery has found a place as an equalizer. The function of the storage-battery is here to take care of the heavy loads or of the peaks of the demands which are made on the substations by the trains; and by absorbing energy from the central station at times of low demand, to smooth out the central station load line, filling up the hollows and cutting off the peaks.

The present paper deals with tests which were made on a large interurban system equipped with nine substations, and the data accumulated shows in a variety of ways the character of the demands which the storage-battery has to meet in substation practice. The data may be said to reveal as many of the faults as of the benefits of the storage-battery in substation practice, and as the intent of all of our engineering investigations is to improve conditions of operation, the faults which have been detected may prove as valuable from having been brought to light as are the measures which are given of the work done by the storage-batteries in improving the general economy of the system.

The tests described were made during the spring of 1902 on the system of the Union Traction Company of Indiana. This company was organized June 28, 1899, and is the consolidation of the Union Traction Company of Anderson, and the Muncie, Anderson and Indianapolis Street Railway Company. Later by the purchase of the local lines of Marion and the building of interurban lines the system has been extended until at the time of the tests it was operating over 160 miles of city and interurban track. About 110 miles of this is interurban road connecting the principal cities of the Indiana gas belt and its location is shown by the

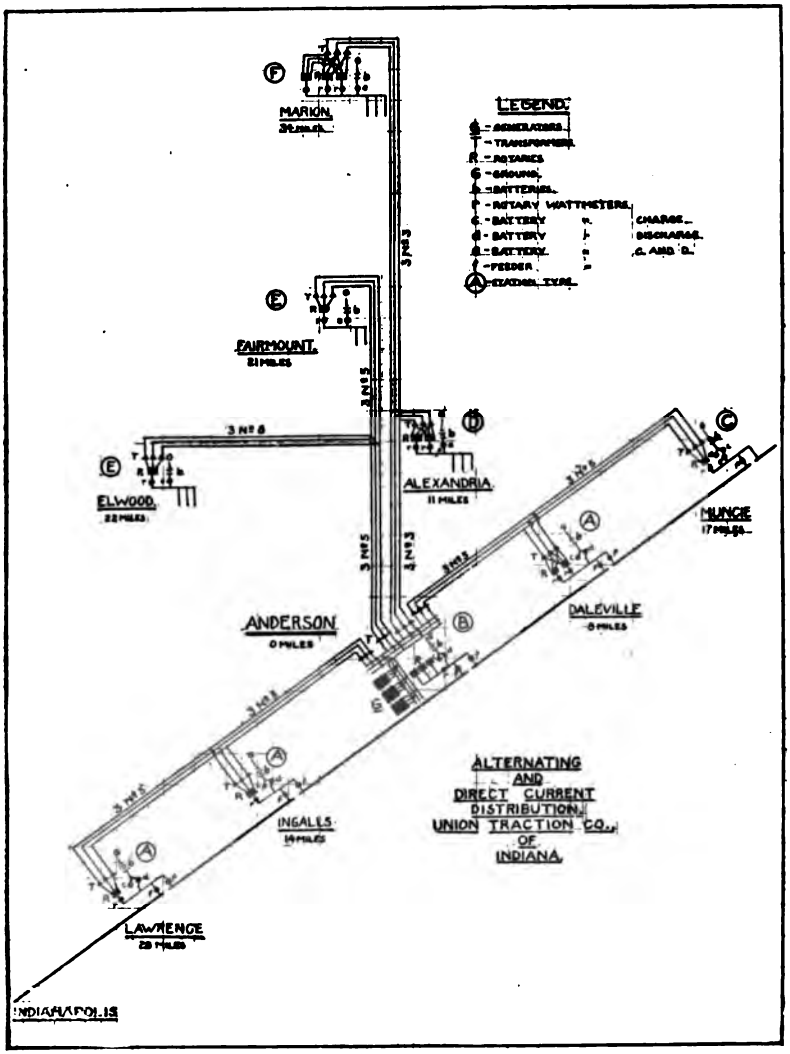


FIG. 1.

chart of Fig. 1, in which diagrammatical representation is given of the transmitting and distributing lines which connect the distributing substations. At the present time this system is greatly extended over what it was at the time of the tests and represents the greatest interurban property in the world. The main power station at which all the power for the entire system is generated is located at North Anderson, adjacent to the interurban line. The substations have been installed at Lawrence, Ingalls, in the main station at Anderson, at Daleville, Muncie, Alexandria, Fairmount, Marion and Elwood.

At the central station the generators deliver electric energy to the load bus-bars at 400 volts. It is then stepped up to 16,000, and transmitted at this potential to the substations, where it is stepped down to 330 volts. Rotary converters then transform the energy from alternating at 330 volts to direct current at 550 volts, the latter being the pressure used on the trolley system. The substation at Ingalls is 15 miles from Anderson, that at Lawrence 28½ miles. These substations receive energy from the same high-tension feeders. The substation at Daleville is 9 miles and that at Muncie 18 miles from the central station. These two stations are also on the same set of high-tension feeders. Alexandria is 11 miles and Fairmount 21 miles from the central station; the substations at these points receive energy from the same set of high-tension feeders. Marion, which is 33 miles from Anderson, and Elwood, which is 21 miles from Anderson, have substations receiving energy in part over the same high-tension feeders. The feeder system supplying these stations branches at Alexandria, one section continuing north and the other due west.

The several sets of high-tension feeders consist of three No. 5 bare B. & S. wires. The substation equipment at Anderson consists of three 250 k.w. rotary converters, a 20 k.w. booster unit and a storage-battery of 264 chloride cells having a one hour capacity of 400 amps. and an 8-hour capacity of 100 amps. In this substation a portion of the low potential current from the main generators is led to the rotary converters through autotransformers instead of through the fifteen 250 k.w. static step-up transformers. Of these 15 static step-up transformers only 12 are kept in service, the other three being a reserve. The substations at Lawernce, Ingalls, Daleville, Fairmount and Elwood are each equipped with three 87.5 k.w. static step-down transformers, one rotary converter of 250 k.w. capacity, a battery of

264 chloride cells, having a one hour capacity of 160 amps. and an 8-hour capacity of 40 amps., and one 8 k.w. booster. The remaining substations, namely, those at Muncie, Alexandria and Marion are equipped with four 175 k.w. static step-down transformers (one being held in reserve), two 250 k.w. three-phase rotary converters, one 16 k.w. booster unit and a storage-battery of 264 chloride cells, having a capacity of 320 amps. at a one hour rate and 80 amps. at an eight hour rate.

The high-tension lines both at the central station and the substations are protected by high-tension lightning arresters and the static transformers are oil-cooled.

A portable substation, equipped with three 87.5 k.w. static step-down transformers, one 250 k.w. rotary converter and a switchboard, has been built for use in case of an emergency arising from accident to one of the rotary converters, or for temporarily increasing the capacity of any one of the established substations. Track has been laid into the substations so that this portable substation car may be run directly into any one of the converter rooms and its rotary leads connected to the direct-current line in the same manner as are the regular substation machines. At the time of the test the portable substation was in use at Marion, increasing the capacity of the Marion substation, where the load was temporarily in excess of the rated capacity of the equipment. The substation buildings are all of the same construction. In addition to the equipment just specified, the substations contain switchboards of white marble, which consist of one A.C. panel and one D.C. panel for each rotary installed, two battery and booster panels and one D.C. panel for each feeder leaving the station. The station instruments are mounted on the switchboards and consist of three A.C. ammeters, one in each leg of the three-phase lines, one D.C. ammeter, voltmeter and wattmeter for each rotary, one D.C. ammeter and voltmeter for the battery and one D.C. ammeter for each D.C. feeder panel. Automatic circuit-breakers and lightning-arresters are provided for outgoing lines.

The substations were equipped with recording wattmeters, in addition to those permanently mounted on the switchboards. These are indicated in Fig. 1. For instance, the substations at Ingalls, Lawrence and Daleville have a switchboard recording wattmeter (*r*) which registers the rotary output, and a temporary recording wattmeter (*c*) for registering the battery charge and a temporary recording wattmeter (*d*) for registering the battery discharge. The wattmeters (*c*) and (*d*) were controlled by a switch which connected the pressure-coil of the wattmeter (*c*) in circuit when the battery was charging and connected the pressure coil of the wattmeter (*d*) in circuit when the battery was discharging. A special observer controlled the position of this switch in accordance with the indications of the battery switchboard ammeter. At Anderson one switchboard recording wattmeter (*r*) registered the output of the three rotaries, the battery charge and discharge being determined by two wattmeters in the same way as at Lawrence, Ingalls and Daleville.

As the Anderson substation supplied power to the local lines in addition to the interurban lines, two special wattmeters (*f* and *f*) were placed in the feeders extending east and west from Anderson. At Muncie two switchboard recording wattmeters are supplied for determining the output of the two rotaries in this substation. The battery charge and discharge was determined by two recording wattmeters (*c* and *d*) as at Lawrence, Ingalls and Daleville, with the addition of the recording wattmeter (*e*) which was permanently connected in the battery lead so that it ran forward when the battery was charging and backward when the battery was discharging. The recording wattmeter (*f*) placed in the interurban feeder registered the amount of the output of the Muncie substation which was delivered to the interurban cars. This substation also supplied the cars of the local line with power. At Elwood and Fairmount the rotary output was determined by the switchboard recording wattmeter (*c*) permanently connected in the battery lead. At Alexandria the same conditions existed as at Elwood and Fairmount except that two switchboard recording wattmeters are provided for determining the rotary output. At Marion the same conditions obtained as at Alexandria except that an additional recording wattmeter (*p*) was placed in the portable substation to determine the output of the rotary. In all, therefore, there were twelve switchboard recording wattmeters in use for determining the output of the rotaries and one temporary recording wattmeter for determining the output of the portable substation rotary. Fifteen temporary recording wattmeters were used for determining the charge and discharge of the storage batteries and three special feeder recording wattmeters for determining the proportions of the output of the Anderson and Muncie substations which were delivered to the interurban feeders.

During the tests the D.C. instruments which have been mentioned, except the feeder ammeters, were read in all of the substations every fifteen minutes. Simultaneously with these readings a polyphase recording wattmeter, which registered the central station output, was read and readings were also taken from recording wattmeters placed in each one of the interurban cars plying between Indianapolis and Muncie.

All of the instruments used in the test were carefully calibrated by being compared with standards. The method of calibrating the recording wattmeters was as follows: the time was taken during which a certain number of revolutions of a wattmeter-disc were made, while during the same time rapid observations were made of the current and voltage fluctuations. From the latter the average of the current and voltage during the time the revolutions of the wattmeter disc were being made were determined. The constant of the wattmeter is found by the formula:

$$K = \frac{\text{Watt hours}}{\text{revolutions}} = \frac{E \times I \times T}{3600 \times R}$$

Where E is the average voltage,
I the average current,
T the time in seconds,
and R the number of revolutions of the disc.

The wattmeters were all calibrated while connected in with the service lines. The constants determined for many of the wattmeters differed widely from those given by the manufacturers. This is probably due to the fact that in many cases the wattmeters ran far below their rated current capacity. This was unavoidable on account of the fact that the capacity of the wattmeters had to be sufficient to take the peak loads. Where the wattmeter was permanently connected in the storage battery leads, as at Muncie, Alexandria, Fairmount, Marion and Elwood, so that it ran both forward and backward, the instrument had to be calibrated for both methods of operation. It was found that the constants of these instruments when running forward were quite different from the constants of the instruments when running backward.

The polyphase wattmeter at the power house was also calibrated, and as the calibration showed its error was probably not greater than those of observation, its readings were assumed to be correct.

EFFICIENCY OF HIGH AND LOW-TENSION DISTRIBUTION LINES.

The arrangement of the high-tension feeders between the central station at Anderson and the several substations has already been described. In determining the efficiency of the high tension distribution system recourse is had to the central and substation records. In Table I. the total outputs of the rotaries in the different substations for the different days of the test are recorded. In Table II. that part of the total output of the main generating station at Anderson is recorded which was delivered to the primary windings of the high-tension transformers. These values are equal to the total output of the generating units as given by the recording wattmeter on the load panel, less the power taken from the primary bus-bars by the rotaries located in the generating station. Table II. also records the total power delivered to the low-tension feeders by the substations which derived their energy from the high-tension system. The D.C. output of Table II. is therefore the sum of the readings of all the rotary wattmeters less the output of the rotaries in the Anderson substation, as these were fed directly from the generating station bus-bars through auto-transformers and not through the high-tension lines. The all-day efficiencies obtained run very close together, averaging 73½ per cent.; this is the efficiency of the high-tension distribution from the low-tension bus-bars in the generating station to the direct current terminals of the rotaries.

In determining the efficiency of the high-tension transmission lines, the amount of energy lost in the raising and lowering transformers, as well as in the rotary converters, had, of necessity, to be determined. The transformers were not worked up to their full capacity; the load on the single, or A and E. stations, Fig. 1 averaging about 40 per cent., the load on the Muncie station averaging about 34 per cent. and that on the Alexandria and Marion stations but 30 per cent. of the total full load capacity of the transformers. By an inspection of the transformer efficiency curve supplied by the manufacturers, it is estimated that the average efficiency at which the transformers worked is not far from 95 per cent. and, as recorded in Table IV., this value has been used. To obtain the average working efficiency of the rotary converters, a special test was made on the rotaries in the Alexandria substation, beginning on April 27th and ending on April 30th. In arranging for this test an alternating current recording wattmeter was connected in each of the three alternating current leads of one of the rotaries. The sum of the readings of these wattmeters gave the rotary input, while the output was given by the regular direct current station recording wattmeter:

the instruments were read every hour. From these two sets of readings the efficiency was estimated by determining the ratio of the output to the input of the rotaries over selected periods of one, six and twelve hours; the results of these efficiency determinations are given in Table III. and plotted in Fig. 25. It will be observed that the load on the rotary under test varied from 23 to 54 per cent. of the capacity of the rotary, and that the average of the efficiency record is practically 88 per cent.; and since all of the rotaries installed are identical in design and construction, it may be safely assumed that the efficiency as determined above for one rotary is applicable to all the rest of the rotaries. Further, the average load on the substations varied between 30 and 40 per cent., of the capacity of the rotaries in the several substations, and, therefore, the records in Table III. show that the rotary under test was subjected to an average degree of loading. The figure, 88 per cent., has been used, as recorded in Table IV., in determining the energy lost in the rotaries.

Having the transformer and rotary efficiencies estimated with a fair degree of accuracy, it was a simple matter to determine the input to the high-tension line from the input to the step-up transformers, and the output from the high-tension line from the output of the rotaries. Taking the ratio of these values we find that the average efficiency of the high-tension distributing system is 93 per cent., being practically constant for the three days. This result indicates that the efficiency of the high-tension system in operation is somewhat less than the efficiency for which it was calculated. When installed it was estimated that the high-tension lines would absorb 7 per cent. of the energy transmitted when the system was working under full load; inasmuch as the average load was not in excess of 40 per cent. of the capacity of the system, the efficiency shown by the test is lower than what would be expected.

In determining the efficiency of the low-tension distributing system, the ratio is taken of the total power delivered to the cars to the total power delivered into the low-tension feeders from the substations. The determination of the amount of power supplied by the substations to the low-tension distributing system is given in Table V. Owing to the fact that it was only possible to equip the interurban cars plying between Indianapolis and Muncie with the recording wattmeters, the efficiency of only this portion of the low-tension transmission system was made. On account of the fact that the Muncie substation supplied the power for the local cars in Muncie, it was necessary to install a special recording wattmeter in the interurban feeder from the Muncie substation. The Anderson substation also supplied power for the operation of the local cars in Anderson; and accordingly a wattmeter had to be placed in the feeders which run East and West from the Anderson substation supplying power to the interurban cars.

Circuit-breakers were inserted at the city limits in Muncie and in Anderson. This arrangement effectively prevented any error entering into the efficiency determinations, inasmuch as the wattmeters on the interurban cars were read whenever these circuit-breakers were passed. In determining the power delivered to the low-tension distributing system from the substations, the battery charges were in each case subtracted from the sum of the rotary outputs and the battery discharges, except in the case of the Anderson and Muncie substations where the results were obtained directly from the feeder wattmeters. The results of the efficiency determinations show that the efficiency of the low-tension distribution system over the Anderson-Muncie division is about 5 per cent. higher than that over the Indianopolis-Anderson division. The loss of the former amounts to about 22 per cent. and that of the latter about 28 per cent. of the energy delivered to the low-tension feeders. The average efficiency of the low-tension transmission for the three days of the test over the Muncie-Indianapolis lines was 74½ per cent., which shows a loss in the distributing system of 25½ per cent. of the energy delivered by the substations to the feeders.

STORAGE-BATTERY TESTS.

Having obtained a fair understanding of the conditions which existed over the system, we can now profitably turn to the records which were made of the storage-battery performances in the various substations. The connections in the substations are shown in Fig. 26. From these it will be seen that the booster is so connected in the battery circuit as automatically to adjust the battery voltage to the demand on the substation; in other words, the battery charges and discharges automatically, feeding out to the line when the demand is above a given amount, and being charged by the rotaries when the demand falls below that amount. The potential at which the battery will float on the system, or the demand on the system corresponding to which the battery is inactive, can be adjusted at any desired point by the switchboard attendant; this fact is to be remembered in connection with the data which is presented.

Prior to the main test, a special test was made of the storage-battery in the Ingalls substation on the 23d of March, 1902, between 8:15 A.M., and 8:00 P.M. The record of the rotary output during this time is given in Fig. 2; the battery current and the battery and line voltage are not plotted in Fig. 2, but these quantities are given in Fig. 3 for the period of the test between 5:00 and 7:00 o'clock. The results are plotted to a much larger time-scale in Fig. 3 than in Fig. 2 and more perfectly show the load variations.

The records in Fig. 2 are given to show the load cycle on the Ingalls substation. The cycle is caused by the manner in which the local interurban cars and the limited interurban cars pass the substation. At the even hour the local interurban cars running both East and West are so far from the station as to make but a slight demand upon it for power; however, at twenty-five minutes past the hour a local interurban car passes going East and at thirty-five minutes past the hour another passes going West; this cycle was repeated each hour. The limited interurban cars approach and pass the station just before and just after the even hours every third hour, *i.e.*, at five minutes to twelve a limited car passes the station, going East, and at five minutes past twelve a limited car passes the station, going West at five minutes to three another limited passes the station, going East, and at five minutes past three a limited passes the station, going West. By the letters I E for the local interurban going East and I W for the local interurban going West, by L E for the limited interurban going East and L W for the limited interurban going West, the times at which the interurban cars pass the Ingalls substation are indicated on Fig. 2. It will be noted that the points of maximum demand usually fall about the time (according to the schedule) the cars should be passing the substation.

The maximum capacity of the rotary of this substation is 500 amperes, and it will be noted that the load on the rotary during the twelve-hour test rarely exceeded this maximum amount, the average load being between 200 and 250 amperes. The readings from which these curves are plotted were taken with great care, Fig. 2 being plotted from readings taken at thirty-second intervals and Fig. 3 from readings taken at fifteen-second intervals. In Fig. 3 the battery current and the rotary current are shown by full lines. The algebraic sum of the battery and rotary currents give the dotted line which crosses the rotary current line; this

dotted line shows the total demand on the substation by the trains. The line voltage is shown by a full curve at the top of the chart, the dotted curve being the battery voltage. The maximum discharge rate for one hour of the battery in the Ingalls substation is 160 amperes. The maximum demand made upon the battery in one instance was as high as 270 amperes and in another ran up to 175 amperes; in general, however, the demand upon the battery was not especially heavy, not often exceeding 100 amperes, and, frequently for a considerable period of time falling within the eight-hour discharge rate of 40 amperes. The greatest instantaneous demand on the station recorded in Fig. 3 occurred at 6:55 P. M., when the load momentarily ran up to 700 amperes. The accuracy of the results plotted in Fig. 3 is indicated by the fact that when the battery is discharging the battery voltage always drops below the line voltage, and, that when the battery is charging, the battery voltage runs above the line voltage.

The curves of Fig. 3 have been made chiefly useful in determining the " *efficiency of equalization*," of the battery in this substation. The efficiency of equalization designates the extent to which a storage-battery is successful in maintaining the demand on a rotary converter or generator at the true average of the load under the variable conditions of service. If a line be drawn that represents the average load on a station and the rotary load curve coincides with it, the battery may be said to have an "efficiency of equalization of 100 per cent."; *i.e.*, it performs its function as an equalizer perfectly. On the other hand, if the rotary curve follows the line load-curve, the battery is obviously inactive, and,therefore, its efficiency of equalization is zero. The efficiency of equalization may then be defined as the ratio of that portion of the rotary load-curve that is above the average load curve to that portion of the line load-curve that is above the average load-curve. In the present instance the efficiency of equalization of the battery works out to be 11.9 per cent.; *i.e.*, the battery only reduces the irregularities in the demand on the substation from the line by 11.9 per cent of what the demand on the rotaries would be if the battery so equalized the load that the rotaries worked constantly under a load equal to the average of the variable demand made upon the substation by the cars

The result of these considerations indicates that the adjustment in the substation was somewhat faulty; the booster and battery are not so arranged as to enable the battery to respond with sufficient promptness in taking care of variations in the load which occur. It is not a case of the battery not having sufficient capacity for the duty which it is called upon to perform, as the maximum variations in the load seldom exceed 250 amperes and more frequently run within 150 amperes. No attempt was made to remedy the faulty action of the booster set, as until the recorded data could be worked up no estimate could be made of the performance of the battery in this particular.

In order to determine the duty performed by the boosters in the substations, a determination has been made from the readings taken in the Lawrence substation during the main test of the average amount of boosting done by the booster during each of the three days. On the first day, April 17th, the line voltage averaged 15.5 volts higher than the battery voltage; on the second day, the line voltage averaged 31 volts higher than the battery voltage and on the third day 10.6 volts higher than the battery voltage. The Ingalls and Lawrence substations, as indicated by Table I., have about the same rotary output in k.w. hours per day. The average current demand made on these substations is not far from 175 amperes and, consequently, the normal demand made upon the boosters is from 1.75 to 5.25 k.w. The capacity of the boosters in the Ingalls and Lawrence substations is 8 k.w., and it is probable that very frequently so heavy a demand is made upon the boosters that they have not the capacity to enable them adequately to meet the demand. If the boosters had been equipped with a heavy flywheel, the chances are that the " efficiency of equalization " of the storage-battery would be very greatly improved over what the results recorded make it possible to report.

At the time of planning for the tests which were made on the storage-battery it was hoped that data would be accumulated which would make it possible to determine the exact commercial efficiency of the storage-battery equipments of the various substations. When, however, it is remembered that it was not possible to subject the storage-batteries to any definite cycle of loading, and that it is extremely difficult when a definite cycle of loading does not exist to keep a sufficiently accurate hold on the battery to admit of its being brought to the same condition once in 24 hours, the difficulties in the way of obtaining any accurate efficiency estimates are at once apparent.

In scanning the records, efforts were made to obtain efficiency indications by a comparison of wattmeter readings made at times when the battery current was zero and the voltage the same, on the assumption that within reasonably short periods of time the variations in the battery-solution would not be sufficient to affect the results materially. Inspection, however, proved that the variations which took place in the load upon the battery were entirely too rapid for the voltage record to be sufficiently reliable for the purpose contemplated, and, therefore, all attempts to determine the performance of the batteries in terms of commercial efficiency were abandoned. In lieu of these determinations an effort has been made, by virtue of the presentation of the recorded data which is given in Figs. 4 to 23, to throw some light on the service which the different batteries were required to render.

Figs. 4, 5, 6 and 7 relate to the battery in the Lawrence substation. Fig. 4 is the load-curve for the three days of the test on this battery. The ordinates represent the k.w. hour load for 4-hour periods plotted above the mean time of the period. For instance, the ordinate which determines the peak in the afternoon of the third day gives the k.w. hour output of the substation between 4 and 8 P. M., and is plotted over the 6 P. M. abscissa. The curves of Fig. 4 therefore indicate the demand made on the substation by the cars during 4-hour periods. In Fig. 5 the charge and discharge of the Lawrence substation battery is also shown for 4-hour periods. For instance, during almost any period of four hours the battery is both charged and discharged and the total charge and discharge values common to a 4-hour period are plotted over the center on that period. For instance, the charge between 12 and 4 P. M. of the second day was 26 k.w. hours and the discharge during the same period was 19 k.w. hours.

The curves of Fig. 6 show the excess of the charge over the discharge or of the discharge over the charge in k.w. hours for 4-hour periods. In other words, the areas of Fig. 6 are the algebraic differences of the charge and discharge areas of Fig. 5. From these, therefore, we can determine the total charge or discharge over the discharge or charge for any 4-hour period. For instance, between 8 and 12 P. M. of the second day the battery had an excess of charge over discharge equal to 40 k.w. hours, while between 12 and 4 A. M. of the third day the battery was discharged more than it was charged by an amount of 30 k.w. hours. Fig. 7 shows the rate at which the battery was charged or discharged in excess of the discharge or charge during any 4-hour period. For instance between 8 and 12 P. M of the third day the battery

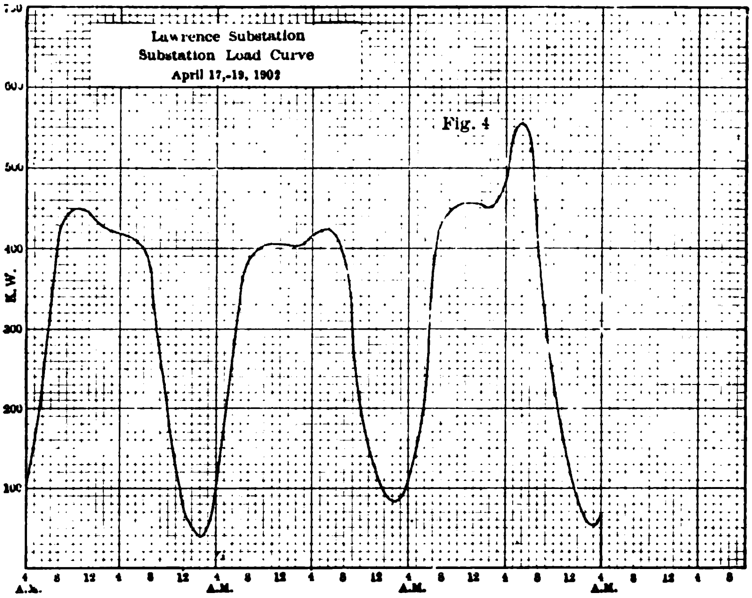

Lawrence Substation
Substation Load Curve
April 17,-19, 1902
700
600
500
400
300
200
100
K. W.
4
8
12
4
8
12
4
8
12
4
8
12
4
8
12
4
8
12
4
8
12
4
8
A.M.
A.M.
A.M.
A.M.

Fig. 4

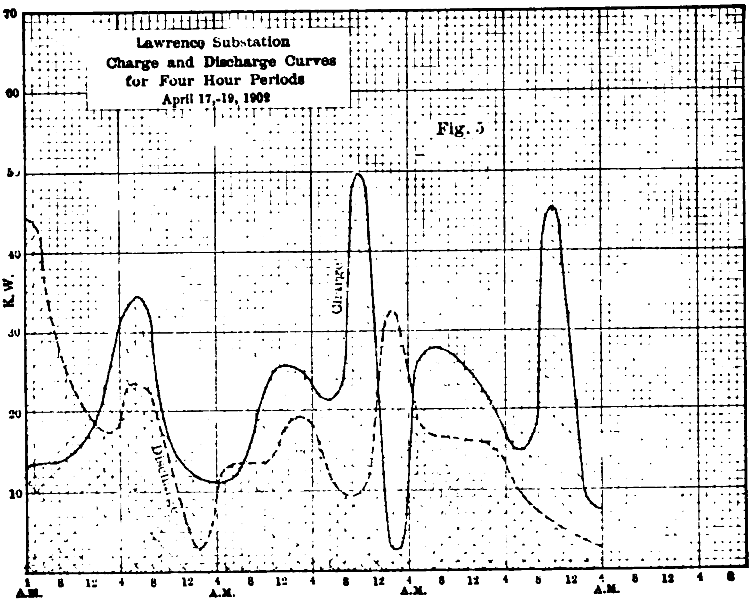
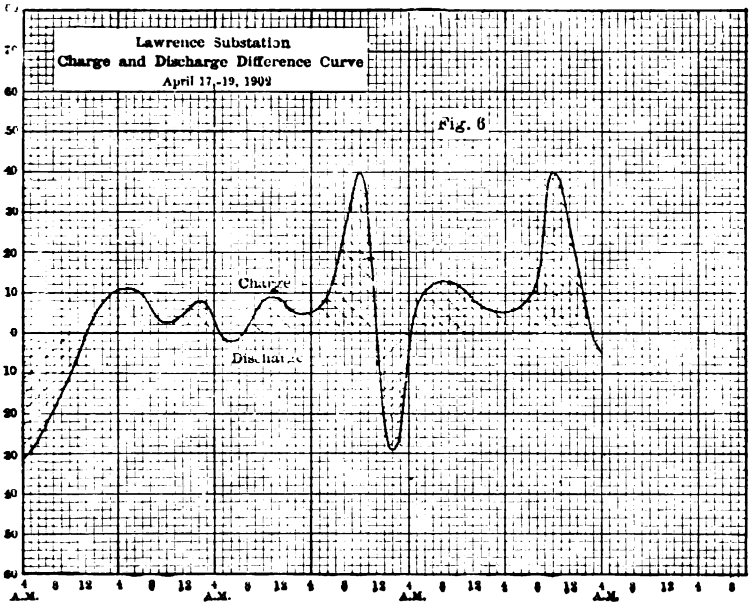
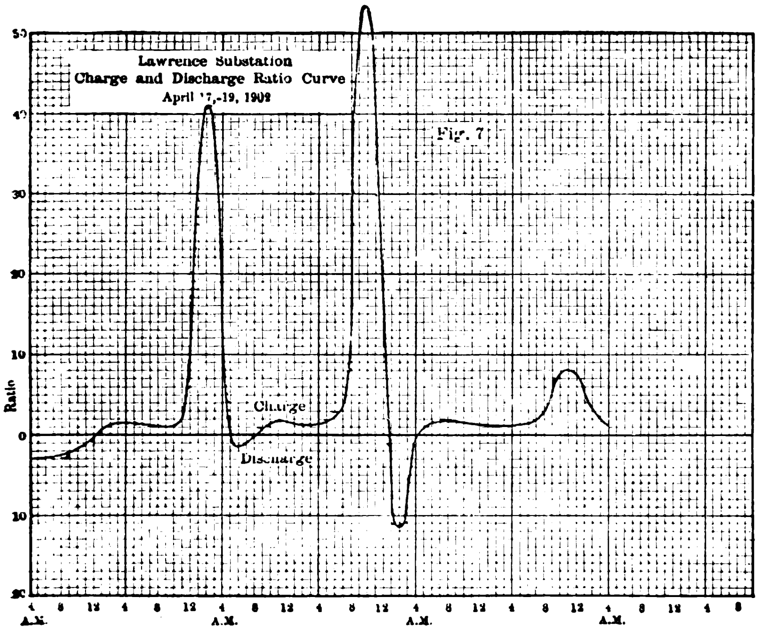

Lawrence Substation
Charge and Discharge Curves
for Four Hour Periods
April 17,-19, 1902
70
60
50
40
30
20
10
K. W.
Charge
Discharge
4
8
12
4
8
12
4
8
12
4
8
12
4
8
12
4
8
12
4
8
12
4
8
A.M.
A.M.
A.M.
A.M.

Fig. 5



Lawrence Substation
Charge and Discharge Difference Curve
April 17,-19, 1902

Fig. 6



Lawrence Substation
Charge and Discharge Ratio Curve
April 17,-19, 1902

Fig. 7

received a charge eight times greater than the discharge which occurred during this 4-hour period, while between 12 midnight and 4 A. M. of the third day the battery received a discharge which was eleven times greater than the charge which it received during the same period.

An interpretation of Curves 4, 5, 6 and 7 considered collectively indicates with a good degree of accuracy the kind of service which the Lawrence substation battery rendered during the three days of the test. On the first day in the forenoon the battery was discharged more than it was charged, but the rate of discharging in the morning of the first day was not great. Early in the morning of the third day the battery received about the same discharge and was charged during the same period only a very little, so that the rate of charge for this time was quite high. Between 8 and 12 P. M. of the second day, as shown by Fig. 5, the battery received a charge of 50 k.w.h. and was discharged 10 k.w.h. The ratio of the charge to the discharge is in this case a little over 5, whereas in the early morning of the same day, although the charge was only 12 k.w.h. the discharge was 3 k.w.h. and therefore the rate of charge over discharge a little over 4. The value of the ratio curves is in determining the accuracy with which the switchboard attendant adjusts conditions in his substation to meet the average demand from the line. If we assume that during any four hour period the charge and discharge of a battery is such as to maintain the battery in the same average condition during this time, the ratio curve will be a straight line displaced 1¼ points above the zero line, if the commercial efficiency of the battery is 80 per cent.

Figs. 8, 9, 10 and 11 are plotted from the data obtained from the test of the Ingalls substation in the same manner as were the curves for the Lawrence substation just discussed. However, Table VII. indicates that the battery in the Ingalls substation was worked a little harder during the three days than was that in the Lawrence station. The working conditions in the Ingalls substation are very good. It will be noted that the ratio curve during most of the time runs along between the positive value of one and two, indicating that during any 4-hour period the battery was made to charge slightly more than it discharged. The performance for the three days as shown in Fig. 7 indicates an efficiency of 74 per cent. for the battery; this efficiency being taken as the ratio of the charge to the discharge during the three days. Had the switchboard attendants been a little more careful

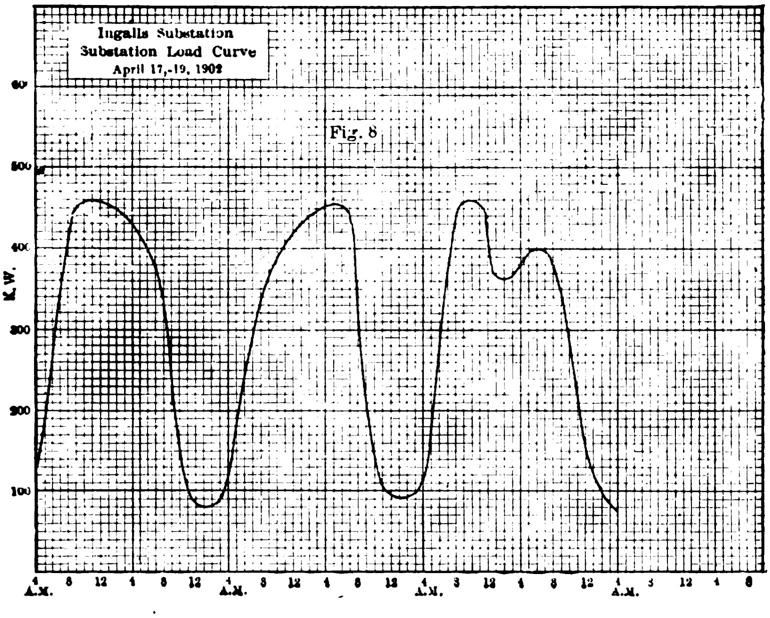

Ingalls Substation
Substation Load Curve
April 17,-19, 1902
K.W.
600
500
400
300
200
100
4 A.M.
8
12
4
8
12
4 A.M.
8
12
4
8
12
4 A.M.
8
12
4
8
12
4 A.M.
8
12
4
8

Fig. 8

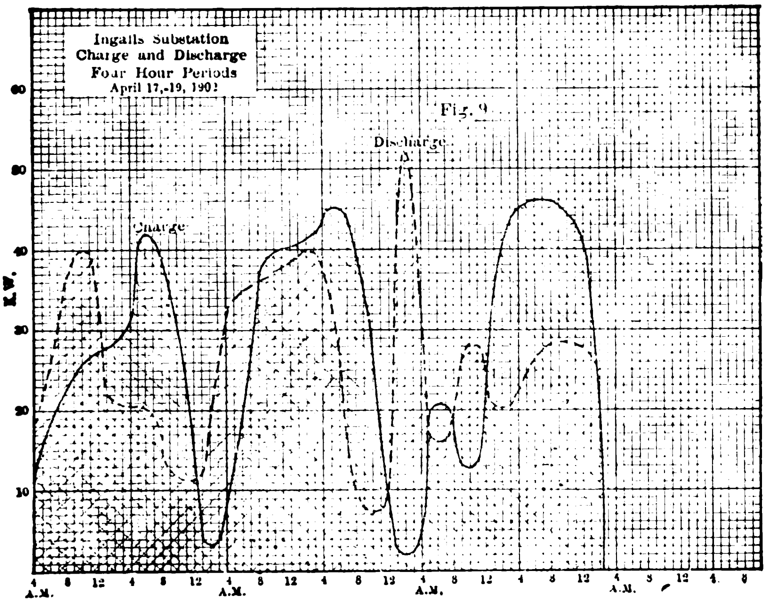

Ingalls Substation
Charge and Discharge
Four Hour Periods
April 17,-19, 1902
K.W.
60
50
40
30
20
10
Charge
Discharge
4 A.M.
8
12
4
8
12
4 A.M.
8
12
4
8
12
4 A.M.
8
12
4
8
12
4 A.M.
8
12
4
8

Fig. 9

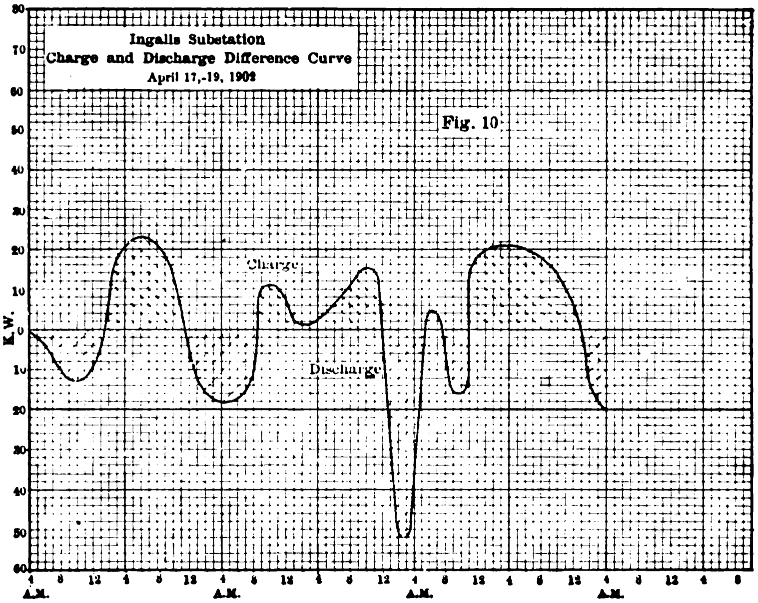

Ingalls Substation
Charge and Discharge Difference Curve
April 17,-19, 1902
Charge
Discharge
K.W.
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
4 A.M.
8
12
4
8
12
4 A.M.
8
12
4
8
12
4 A.M.
8
12
4
8
12
4 A.M.
8
12
4
8

Fig. 10

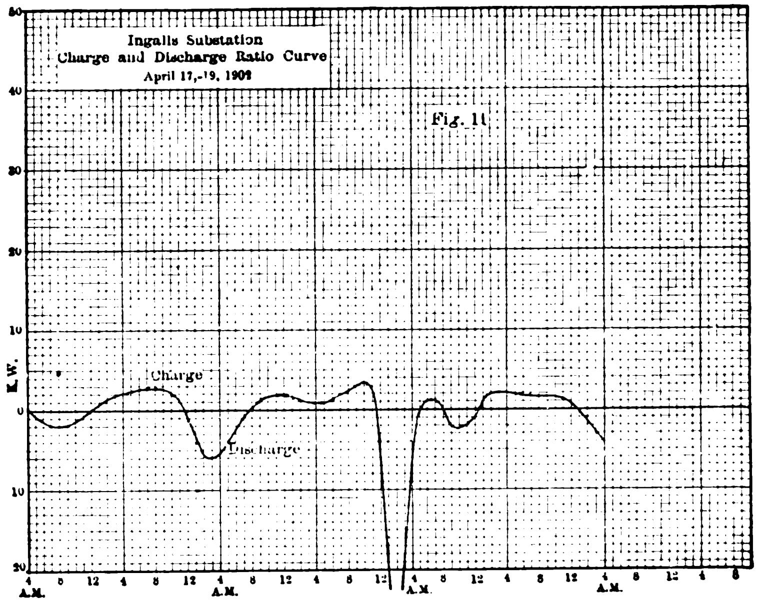

Ingalls Substation
Charge and Discharge Ratio Curve
April 17,-19, 1902
Charge
Discharge
K.W.
50
40
30
20
10
0
10
20
4 A.M.
8
12
4
8
12
4 A.M.
8
12
4
8
12
4 A.M.
8
12
4
8
12
4 A.M.
8
12
4
8

Fig. 11

the battery could have been carried through the test working on a maximum efficiency basis. The term maximum efficiency is here used to indicate the best efficiency at which the battery can be operated.

The 4-hour period which has been made the basis in this discussion has been assumed arbitrarily, for the reason that it seems long enough to insure a proper gauge of the average performance and not too long to obscure it. The average performance of the Ingalls substation battery for the three days is more nearly what it should be than that of any other of the stations tested. The station shows an efficiency for the three days of 88 per cent., which is 3 per cent. above the efficiency claimed for the batteries by the manufacturers. The ratio curve maintains a good positive value which would have been greatly improved had not the two discharge peaks between 12 and 4 A.M. of the first and third days occurred.

Figs. 12, 13, 14 and 15 are plotted from the data at the Anderson substation. These curves indicate the extremely variable conditions which exist at this substation owing to the fact that local and interurban cars bring about very irregular conditions of load. In spite of the fact that this battery shows heavier charge and discharge periods of long duration than that of any of the other substations, the ratio curve is comparatively good, being in fact as good as any, and much better than the ratio curve of the Daleville substation, in which the tax upon the battery was much less marked. The Daleville curves which are shown in Figs. 16, 17, 18 and 19 indicate quite clearly that the battery was practically floating on the system most of the time, as during no 4-hour period did its discharge over its charge exceed 14 per cent. of the 4-hour discharge rating of the battery. The efficiency of the battery for the three days is 76 per cent.

The substation at Muncie, next to that at Anderson, shows the largest output of any of the substations for which curves have been plotted. As indicated by the ratio curve of Fig. 23, the discharge of this battery was very much in excess of the charge and in fact for the three days the station shows an efficiency of 112 per cent. As at Anderson so at Muncie the local street railway cars make an irregular demand upon the station. This largely accounts for the fact that no special discharge cycle is noticeable. The charge cycle, however, is fairly regular as shown by Fig. 21. Most of the substations have a fairly uniform charging cycle. This cycle is particularly well brought out in the case of the

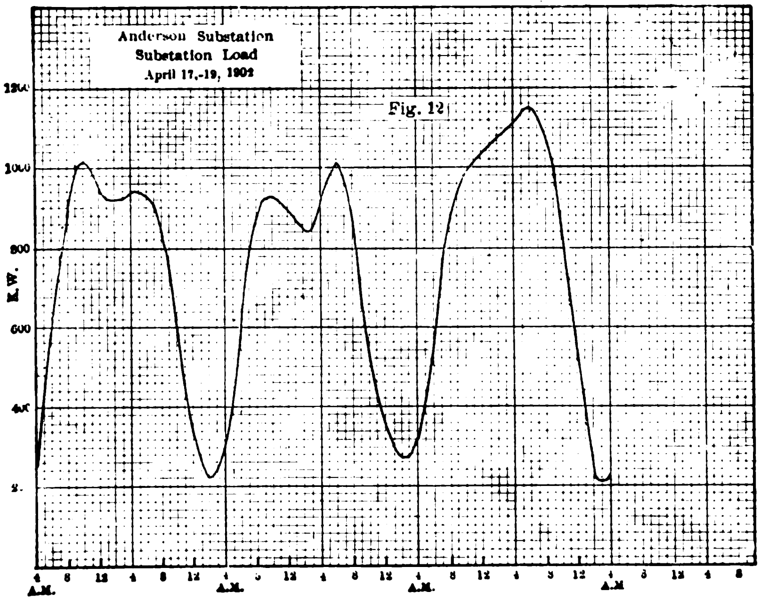

Anderson Substation
Substation Load
April 17,-19, 1902
K.W.
1200
1000
800
600
400
200
4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8
A.M.
A.M.
A.M.
A.M.

Fig. 12

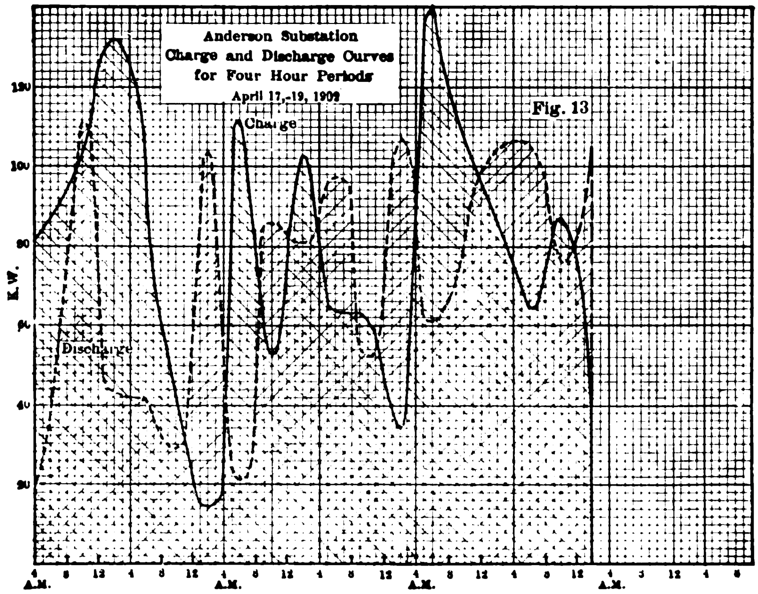

Anderson Substation
Charge and Discharge Curves
for Four Hour Periods
April 17,-19, 1902
Charge
Discharge
K.W.
120
100
80
60
40
20
4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8
A.M.
A.M.
A.M.
A.M.

Fig. 13

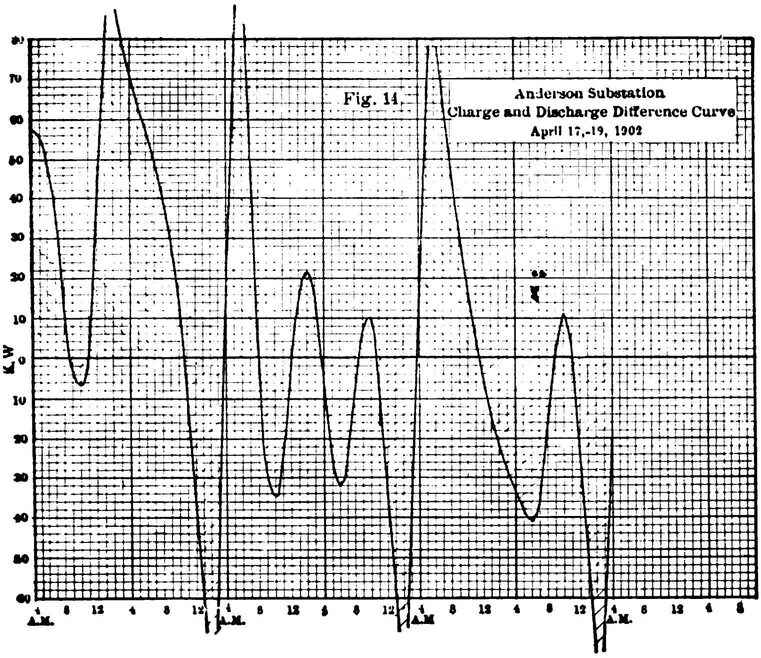
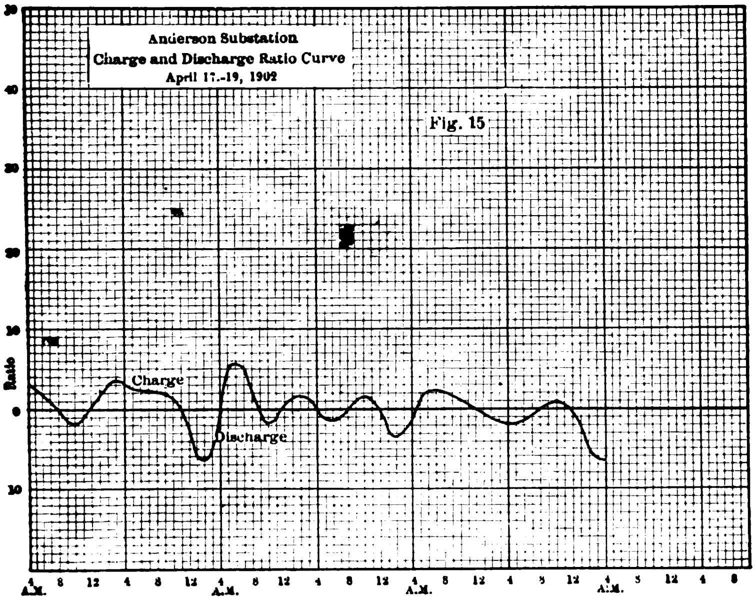


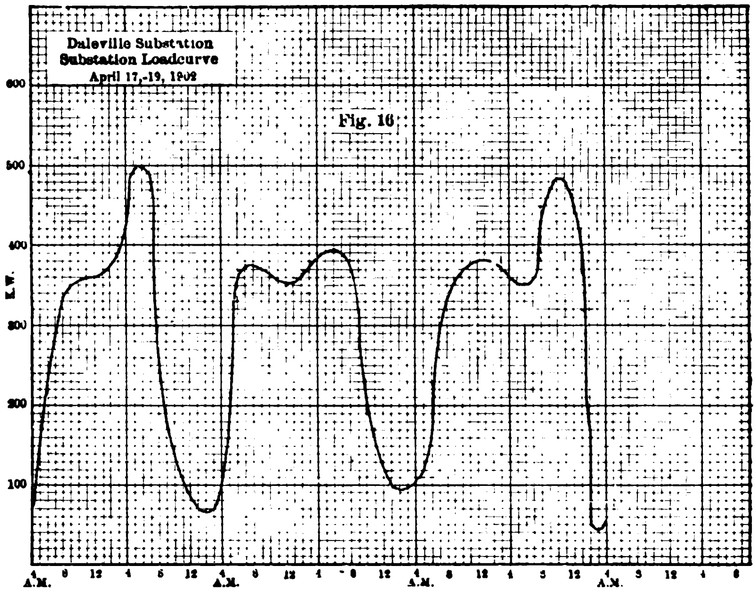
Fig. 14.

Anderson Substation
Charge and Discharge Difference Curve
April 17,-19, 1902



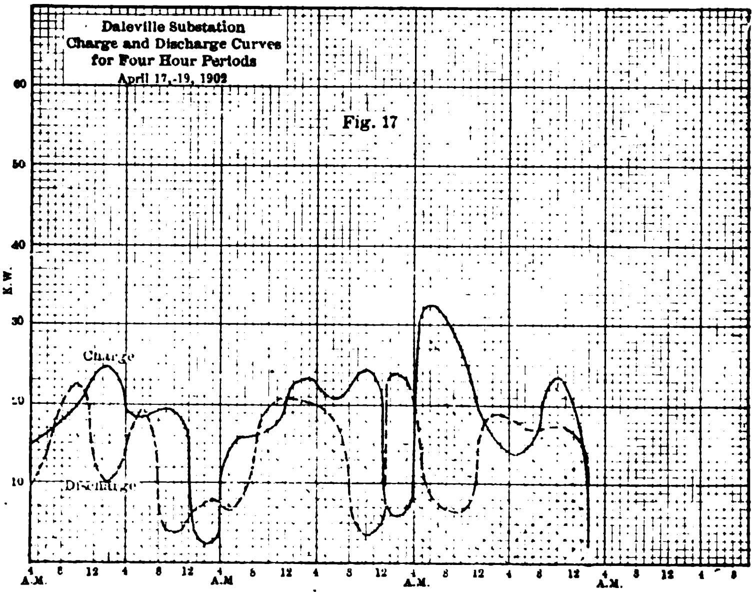
Anderson Substation
Charge and Discharge Ratio Curve
April 17.-19, 1902

Fig. 15



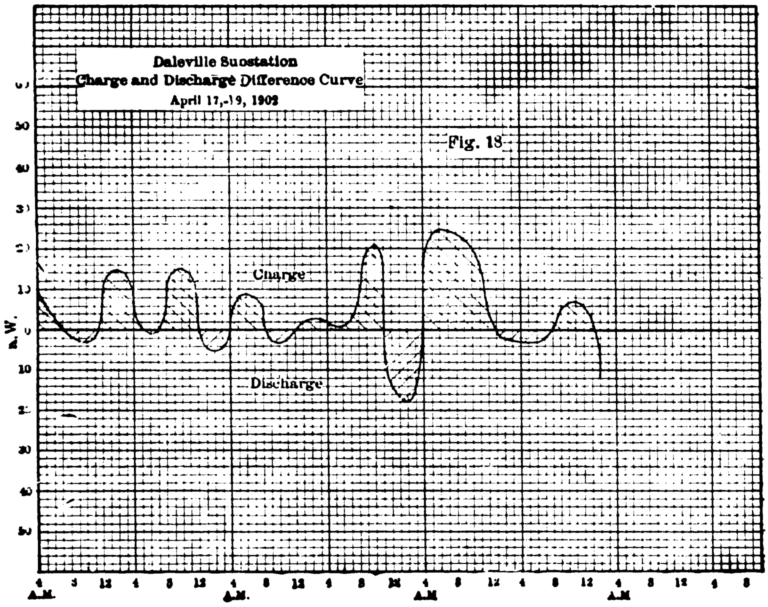
Daleville Substation
Substation Loadcurve
April 17,-19, 1902

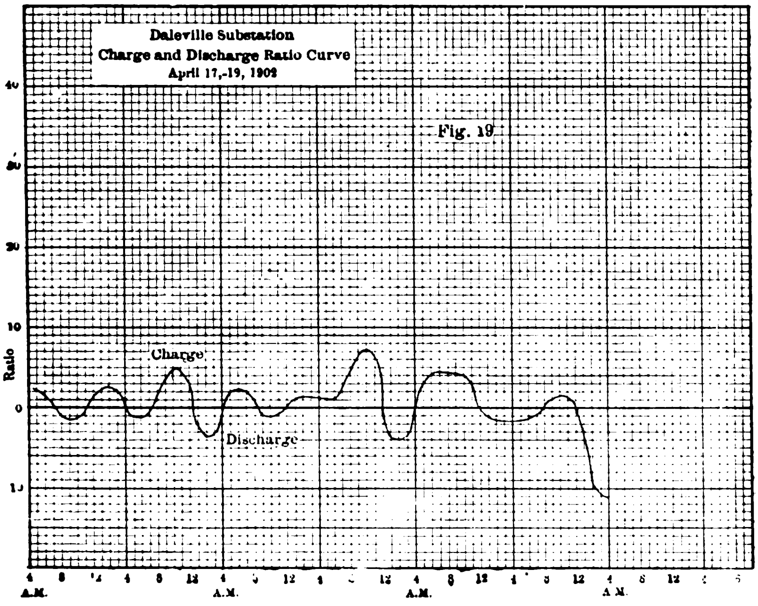
Fig. 16



Daleville Substation
Charge and Discharge Curves
for Four Hour Periods
April 17,-19, 1902

Fig. 17


Daleville Substation
Charge and Discharge Difference Curve
April 17,-19, 1902
Fig. 18
Charge
Discharge
K.W.
50
40
30
20
10
0
10
20
30
40
50
4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8
A.M.
A.M.
A.M.
A.M.


Daleville Substation
Charge and Discharge Ratio Curve
April 17,-19, 1902
Fig. 19
Charge
Discharge
Ratio
40
30
20
10
0
10
4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8
A.M.
A.M.
A.M.
A.M.

Lawrence substation on the second and third days. The charging cycle shown by the curves of the second day in Fig. 9 is probably characteristic of the Ingalls substation. The charge curve of the third day in Fig. 13, it is believed, represents the ordinary charge cycle of the Anderson battery; but for the depression which occurred on the second day during the 8 to 12 A. M. period the charging cycle would have repeated itself during the two last days of the test. The charging cycle of the Daleville substation is not specially characteristic in outline. The first and second days, however, show in general what is to be expected. In the case of Muncie the first and third days are probably more representative of the charging cycle in this station than is the second day.

It very frequently happens that for a while in the early morning the generators in the central station at Anderson are shut down. During these periods such trains as may be operating are supplied with energy from the substation storage batteries. For instance, none of the generators was in service between 1.30 A. M. and 4.15 A. M. on April 18th and none of them was in service between 1.30 A. M. and 4.15 A. M. on April 19th. Here then we have two periods of 2.75 hours during which such trains as were operated were supplied with power from the storage batteries. This condition of rest in the central station is reflected in the curves of Figs. 5, 9, 13, 17 and 21 by the discharge peaks which are shown between 12 midnight and 4 A. M. of April 19th. All of the batteries were then required to discharge quite heavily. The demand which was made upon the Lawrence, Ingalls and Anderson substations being particularly heavy. Between 12 midnight and 4 A. M. on April 18th, owing to some local cause a demand was made upon the battery in the Anderson substation. On the morning of the 18th, however, none of the other substations is carrying any special load except the Muncie substation. The Muncie battery discharge curve as shown in Fig. 21 differs very markedly from the discharge curves of the other substations owing to the fact that during the whole of the three days the average of four hours never falls below 44 k.w.h. nor rises above 85 k.w.h. In other words, this battery maintains a discharge rate averaging closely 58 k.w.h. for each 4-hour period during the three days. There is evidently " something doing " in Muncie all the time.

Tables VII., VIII. and IX. contain data which show the degree to which the storage-batteries in the substations were worked over 4-hour periods. The Ingalls substation developed

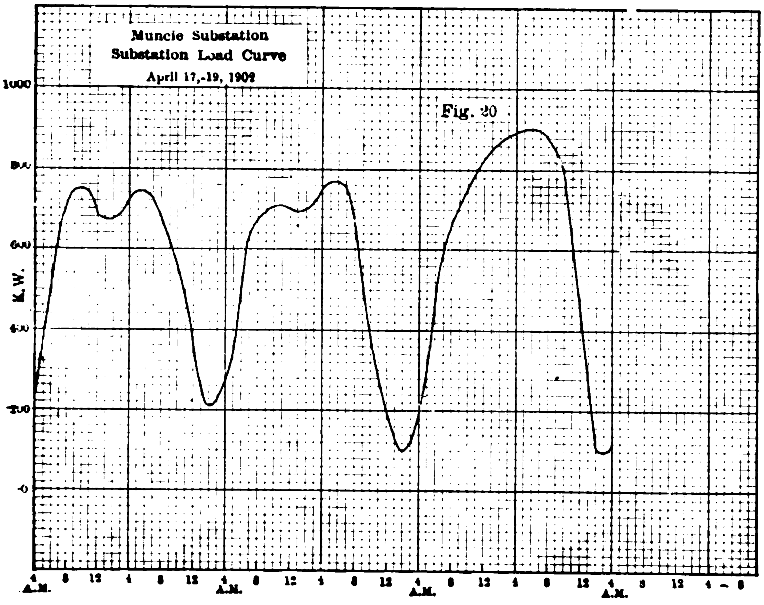

Muncie Substation
Substation Load Curve
April 17,-19, 1902
1000
800
600
400
200
0
K.W.
4 A.M. 8 12 4 8 12 4 A.M. 8 12 4 8 12 4 A.M. 8 12 4 8 12 4 A.M. 8 12 4 – 8

Fig. 20

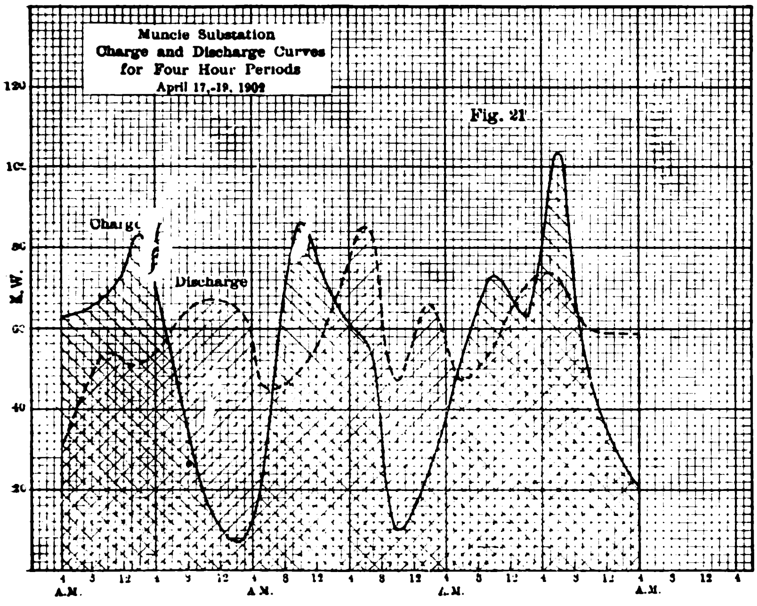
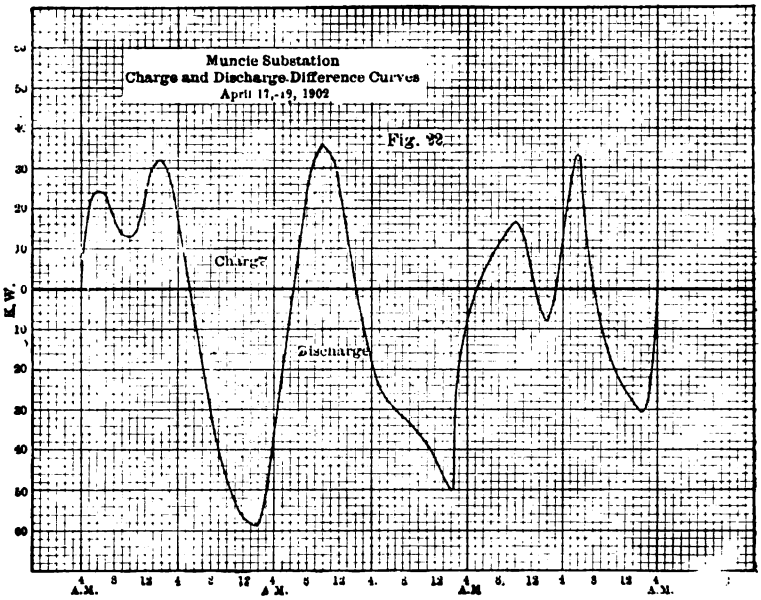
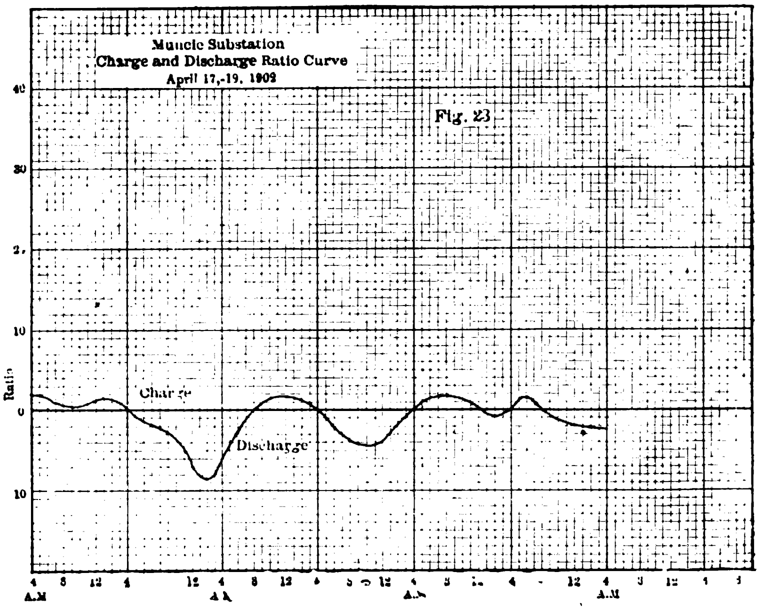

Muncie Substation
Charge and Discharge Curves
for Four Hour Periods
April 17,-19, 1902
120
100
80
60
40
20
K.W.
Charge
Discharge
4 A.M. 8 12 4 8 12 4 A.M. 8 12 4 8 12 4 A.M. 8 12 4 8 12 4 A.M. 8 12 4

Fig. 21



Muncie Substation
Charge and Discharge Difference Curves
April 17,-19, 1902

Fig. 22.



Muncie Substation
Charge and Discharge Ratio Curve
April 17,-19, 1902

Fig. 23

the highest discharge performance, as during the four hours between 12 midnight and 4 A. M. on April 19th, it developed 39 per cent. of its discharge capacity. The Marion, Anderson and Muncie batteries never developed more than 28 per cent. of their discharge capacity over a 4-hour period, and at Daleville the discharge performance during a 4-hour period did not exceed 14 per cent. These figures all go to show that as gauged by the average demand on the substations, the batteries are amply large enough to take care of variations in the demands made on the substations by the trains. It is confidentally believed, however, as has already been pointed out in the discussion of the special test on the storage-battery at the Ingalls substation (see Figs. 2 and 3), the motors driving the booster armatures were not heavy enough to hold up to the momentary demands which rapid changes in the load bring upon the substations, assuming the booster field windings are correctly designed. Proper adjustment would undoubtedly cause the batteries to show a very much higher charge and discharge k.w. performance during the 4-hour intervals, and they would better serve to reduce the fluctuations reflected through the substations from the trains to the central station. A diminution in the fluctuations of the load on the central station at Anderson will in turn increase the economy of the generating machinery. This is a point to which

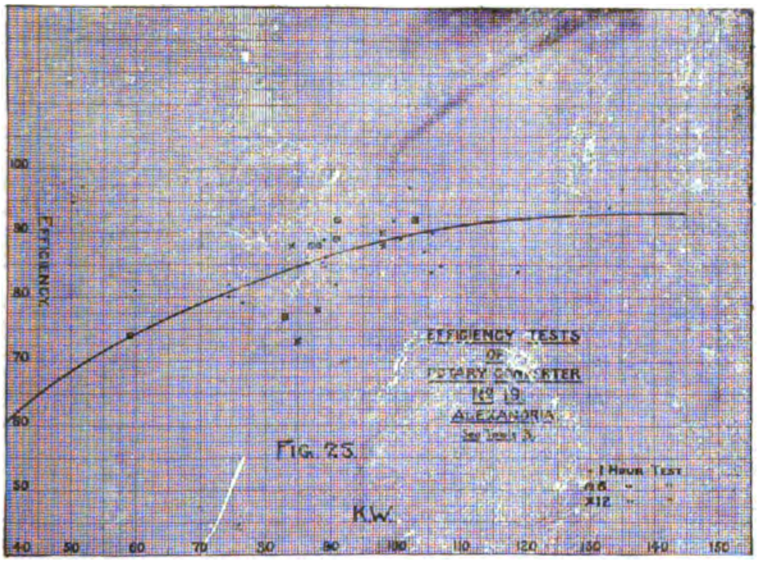


FIG. 25.

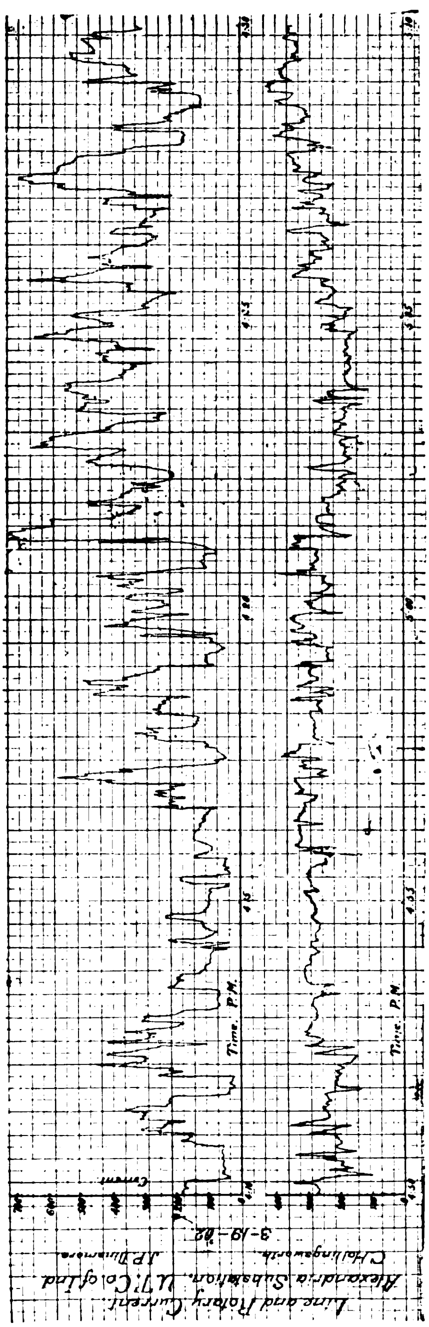
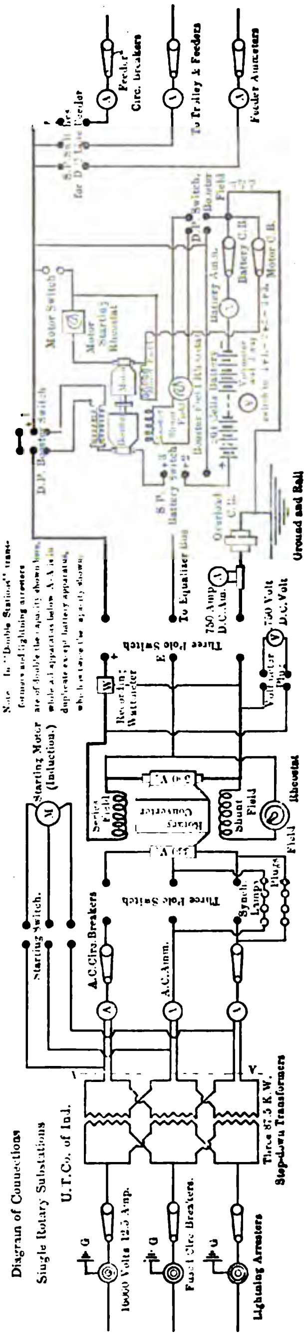


FIG. 24.



Note.—In "Double Stations" transformers and lightning arresters are of double the capacity shown here, while all apparatus below A-A is in duplicate except battery apparatus, which has twice the capacity shown.

FIG. 26.

attention should be given in laying out substations for work of this character, and it is one to which it is believed sufficient attention has not heretofore been directed.

The average commercial performance shown by the batteries during the three days of the test turns out to be 74 per cent. for the Marion battery, 88 per cent. for the Ingalls, 96 per cent. for the Anderson battery, 76 for the Daleville and 112 per cent. for the Muncie battery. Taking the ratio of the total discharge of all of the batteries to the total charge of all the batteries in these five substations, we obtain an aggregate efficiency of 95 per cent. for the batteries in the substation; or, if we average the efficiency values as obtained for the five substations, we get 89 per cent. as the average efficiency of the batteries during this time. These values are high, and yet they continue so for relatively long periods without any special indications of deterioration in the batteries. The batteries were left entirely in charge of the station attendants, and no effort was made at any time to in any way modify the usual performances. The tests indicate that these high efficiencies have been maintained, owing to the fact that only a slight tax has been made upon the capacity of the batteries by the service to which they are commonly subjected. Of course, the continuation of this kind of service indefinitely would in time make itself felt and cause deterioration in the batteries, a condition indicated by marked changes in the density of the electrolyte and rectified by a special charge being given to the battery at relatively long intervals to bring it back to normal condition. Over the system tested it is the practice to give the batteries a special charge on Sunday morning, thus bringing them back to good normal condition once every seven days. At this time the voltage and density of the electrolyte of each cell is taken and made of permanent record.

SPECIAL INSTANTANEOUS DEMAND TEST.

It was possible during the test to make an exact instantaneous record of the current fluctuations occurring at the Anderson substation on March 10th by the following method: A strip of paper was fastened on a tin holder placed in front of the needle of a millivoltmeter and bent to conform to the path traced by the tip of the millivoltmeter needle. The tin holder was then lowered at a uniform rate in front of the voltmeter needle by a clockwork mechanism. The actual record was made on the paper by a continuous induction coil spark from the end of the needle to the tin back of the paper. Deflections of the millivoltmeter were brought about by placing the instrument in shunt with a sufficient length of the bus-bar to give a considerable deflection. With the apparatus it was possible to obtain records of only twenty minutes duration; and, of course, curves could not be taken at the same time of both the rotary load and line load, as was the case in the Ingalls substation test, the results of which are shown in Figs. 2 and 3; but the instantaneous curves *were* taken under similar conditions of loading.

The upper half of Fig. 24 shows the variation in the demand made upon the Alexandria substation by the interurban cars; this record extends from 4.10 to 4.30 on the afternoon of March 19th. The maximum fluctuation in the load at any given time occurred just after 4.21 P. M., when there was an almost instantaneous demand of 500 amps., the load going from 200 to 700 amps. *instantly*, as nearly as it is possible to read the record.

The instrument was connected to the rotary bus-bar from 4.50 to 5.00 P. M. on the same day. There is no reason to believe that the demand upon the station during this time was very different from the demand upon the station during the time that the instrument was connected to register the line fluctuations. Accordingly, it would seem that on the afternoon in question the substation at Alexandria was working much more efficiently as an equalizer than was the battery at the Ingalls substation at the time the records were made which are recorded in Fig. 3. Owing to an unfortunate accident to the millivoltmeter is was impossible to obtain other instantaneous records than those presented, and, therefore, no estimate can be made of the exact efficiency of equalization of the Alexandria battery. Presumably, however, it is higher than that developed at the Ingalls substation, since the average load shown in the curves of Fig. 24 in both cases runs not far from 350 amps.; and while the upper curve is extremely irregular, the lower curve is comparatively uniform.

The maximum one-hour discharge rate of the Alexandria battery is 320 amps. The curves of Fig. 4 show that the demand on the batteries and rotaries together exceeded this discharge rate about once in every thirty seconds, with periods of very light load between. How much of these peaks the battery actually took is not possible to say, presumably, however, its maximum discharge rate for one hour of 320 amps. was frequently exceeded.

The authors desire to acknowledge their indebtedness to

A. S. Richey, Electrical Engineer of the Union Traction Co., S. Hollingsworth and G. P. Dinsmore for assistance which made the carrying out of these tests possible. Mr. Hollingsworth and Mr. Dinsmore were in immediate charge of the observers who took all readings at the various substations, and to their painstaking care is due the accuracy of the work.

TABLE I.

SUBSTATION ROTARY OUTPUT.

K.W.H

Station.	April 17	April 18.	April 1	Total.
Lawrence	1791	1780	1780	5351
Ingalls	1825	1742	1881	5448
Anderson	4400	4340	4827	13567
Daleville	1670	1690	1706	5066
Muncie	3406	3210	3658	10274
Alexandria	3235	2550	2945	8730
Fairmount	1440	1508	2050	4998
Marion	5330	5865	8040	19235
Elwood	1860	1825	1970	5655
Total	24957	24510	28857	78324

TABLE II.

EFFICIENCY OF HIGH-TENSION LINES, TRANSFORMERS AND ROTARIES.

Date.	A.C.Output* K.W.H.	D.C.Output° K.W.H.	Efficiency.
April 17	28,000	20,557	73.3
April 18	27,270	20,170	73.9
April 19	32,750	24,030	73.3
Total	88,020	64,757	73.5

*This column is the total output of the Anderson generators as given by the recording wattmeter on the load panel, less the Anderson rotary input, obtained by dividing the Anderson rotary output by the efficiency of the rotaries—88%.

°This column is the sum of all the readings of the rotary wattmeters, less the output of the Anderson rotaries, as these were fed directly from the bus bars, through auto-transformers and not through the high-tension lines.

TABLE III.

Results of Efficiency Test, Rotary No. 19.

12-Hour Test.			6-Hour Test.		
Average Load K.W.	Per Cent. Load.	Efficiency.	Average Load K.W.	Per Cent. Load.	Efficiency.
84	33.6	88	88	35.2	88
88	35.2	88	91	36.5	92
98	39.3	88	87	34.9	88
98	39.3	90	88	35.2	88
73	29.2	85	91	36.5	89
78	31.2	88	103	41.2	92
Average ...	....	87.8	77	30.8	83
			85	34.0	89
			59	23.6	74
			Average	....	87

TABLE III. (*Continued.*)

1-Hour Test.

Average Load K.W.	Per Cent. Load.	Efficiency.
60.0	24.0	81.0
74.4	29.8	80.0
74.4	29.8	82.0
76.4	30.5	79.0
78.0	31.2	94.0
86.4	34.6	95.0
89.0	35.5	89.0
91.2	36.0	82.0
99.6	39.8	92.0
100.8	40.5	89.0
102.0	40.8	97.0
104.4	41.7	87.0
105.6	42.1	84.0
105.6	42.1	90.0
106.8	42.9	85.0
118.8	47.5	84.0
133.4	53.3	94.0
135.4	54.0	97.0
Average 96.8	38.7	88.3

TABLE IV.

Efficiency of High-Tension Lines, Transformers and Rotaries.

Quantity.	April 17.	April 18.	April 19.	Total.
Step-up trans. input.............	28,000	27,270	32,750	88,020
Step-up trans. efficiency.........	95	95	95	95
High-tension line input	26,600	25,900	31,070	83,570
High-tension line efficiency.......	93.0	92.0	92.7	92.9
Step-down trans. input..........	24,700	23,800	28,750	77,450
Step-down trans. efficiency	95.0	95.0	95.0	95.0
Rotary input	23,500	22,600	27,360	73,560
Rotary efficiency	88.0	88.0	88.0	88.0
Rotary output	20,657	19,770	24,030	64,557
TOTAL EFFICIENCY	73.3	73.9	73.3	73.5

TABLE V.

Efficiency of D.C. Distribution.

ANDERSON-MUNCIE DIVISION.

Input to Line

	April 17.	April 18.	April 19.	Total.
Anderson Inter. East	73.2	3.0	75.5	181.7
Daleville Rotary	1670.0	1681.3	1706.0	5057.3
Daleville Bat. Dis.	67.0	89.4	77.5	233.9
Daleville Bat. Ch.	75.8	107.1	112.0	294.9
Muncie Inter. West	268.5	268.8	355.0	892.3
Total	2002.9	1935.4	2102.0	6092.3

INPUT TO CARS.

	April 17.	April 18.	April 19.	Total.
Regular cars	1448.2	1435.3	1465.0	4348.5
Special cars	56.9	103.6	173.0	333.5
Total	1505.1	1538.9	1638.0	4682.0
Efficiency	78.2	79.5	77.9	77.7

Anderson-Indianapolis division.

INPUT TO LINE

	April 17	April 18	April 19	Total.
Lawrence Rotary	1780.0	1784.88	2001.0	5565.88
Lawrence Bat. Dis	122.6	101.03	67.1	290.73
Lawrence Bat. Ch	115.2	131.79	147.0	393.99
Ingalls Rotary	1830.0	1703.59	1880.0	5413.59
Ingalls Bat. Dis	98.2	180.15	147.0	425.35
Ingalls Bat. Ch	156.0	140.26	182.0	478.26
Anderson Int. W.	714.0	735.60	1030.0	2479.6
Total	4273.6	4233.2	4796.0	13302.8

INPUT TO CARS

	April 17	April 18	April 19	Total.
Regular cars	3096.8	3060.6	3340.4	9497.8
Special cars	42.4	79.1	26.3	147.8
Total	3137.2	3139.7	3366.7	9643.6
Efficiency	73.5	74.1	70.4	71.3

TABLE VI.

Average D. C. Line Efficiency

Division	April 17	April 18	April 19	Total.
Anderson-Muncie	78.2	79.5	77.9	78.5
Anderson-Indianapolis	73.5	74.1	70.9	72.5

TABLE VI.—Continued.

AVERAGE D. C LINE EFFICIENCY.

Date.	Total Input to Line. K.W.H.	Total Input to Cars. K.W.H	Efficiency. Indianapolis. Muncie.
April 17	6197.3	4644.3	75.0%
April 18	6165.7	4678.6	76.0
April 19	6898.0	5004.7	73.0%
Total	19261.0	14327.6	74.5%

TABLE VII.

SUBSTATION BATTERY OUTPUT.

	April 17 K.W.H.	April 18 K.W.H.	April 19 K.W.H.	Total K.W.H.	Three day Efficiency.
Lawrence Charge	115.2	131.8	147.0	394.0	74%
Lawrence Discharge	123.6	101.0	67.1	290.7	
Ingalls Charge	156.0	140.3	182.0	482.3	88%
Ingalls Discharge...........	98.0	180.2	147.0	425.2	
Anderson Charge	477.4	423.7	503.2	1404.3	96%
Anderson Discharge.........	364.5	446.7	537.9	1348.0	
Daleville Charge	100.3	107.1	112.0	319.4	76%
Daleville Discharge	75.0	89.1	77.5	241.6	
Muncie Charge	293.0	282.0	367.0	942.0	112%
Muncie Discharge	332.0	359.0	365.0	1056.0	
Total Charge				3541.0	95%
Total Discharge				3362.0	
Average..........................					89%

TABLE VIII.

CAPACITY OF SUBSTATION BATTERIES

Battery in Substation at	Battery Discharge Rate in Amperes for			Battery Capacity in K.W.H. when Discharged in		
	1 Hr.	4 Hrs.	8 Hrs.	1 Hr.	4 Hrs.	8 Hrs.
Anderson......	400	160	100	211	337	422
Muncie.......	320	128	80	169	271	338
Lawrence	160	64	40	85	135	169

Batteries at Alexandria and Marion have same capacity as battery at Muncie

Batteries at Ingalls, Daleville, Fairmount and Elwood have same capacity as battery at Lawrence.

TABLE IX.

PER CENT. OF BATTERY CAPACITY DEVELOPED.

	4 Hour Discharge Rating.	Max. Discharge in 4 Hrs K.W.H.		Per Cent. of 4 Hour Discharge Capacity Developed.	
	K.W.H.	Total.	Dif.	Total.	Dif.
Lawrence	135.0	33.0	30.0	24.4	22.2
Ingalls	135.0	52.0	50.0	38.5	37.0
Anderson.........	337.0	111.0	89.0	32.9	26.4
Daleville.........	135.0	24.0	18.0	17.7	21.7
Muncie...........	271.0	85.0	59.0	31.3	

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 30, 1903.

SOME NOTES ON THE OPERATION OF RAILWAY MOTORS IN SERVICE

BY CLARENCE RENSHAW.

Part I.

THE EQUIVALENT EFFECT OF SERVICE LOADS.

A combination of the speed-time and input curves indicates in general the performance of an equipment of railway motors with reference to its external characteristics. Judged from these curves only, a given equipment may be perfectly capable of performing a desired service satisfactorily and yet it may be entirely unsuited for the work, so that further information is necessary. The three factors which limit the safe loads for a given motor are: First, its commutation; secondly, its mechanical strength; and thirdly, the temperature rise of the windings. The capacity in regard to the first and second items is usually very much greater than that with reference to the third. As far as commutation and mechanical strength are concerned, a railway motor could, as a rule, operate continuously with loads which would completely destroy the windings in a single day or less. It is usually the temperature rise which limits the capacity. Owing to these facts, railway motors are particularly subject to misuse. Chosen with reference to their apparent capacity only and without due regard to the loads which they may carry safely, such motors are liable to be applied to work for which they are not suited. The general tendency in such cases is to choose equipments that are too small. It is only in comparatively recent years that the amount of power necessary for operating cars, and the tremendous effect on it of changing such items as the weight of car, speed, and number of stops, have begun to be known accurately. The first railway motors used (based in capacity on the number of horses required for a horse-car) were none too large for the duty required of them; and in the case of each new line of railway engineers have some times hesitated to advise, and owners have usually hesitated to buy, motors larger than those in use on similar existing lines, merely because their cars were to be slightly heavier and the speed a little greater.

When new motors are first installed, the effect of overloads will usually not be apparent at once. The damage done by abnormal temperatures is, as a rule, not instantaneous but gradual. Owing to the inaccessibility of a railway motor when mounted for service, the temperature which it attains is not likely to be noticed unless it is particularly sought for. It is only when a motor has been overloaded sufficiently long to roast coils or make other repairs necessary that trouble is suspected. Even then in seeking the cause of the trouble, overloading pure and simple is the last thing to be thought of; the fault is much more likely to be attributed to defective material or construction. Thus it will be seen that the temperature problem is an important one. A due consideration of the loads which they may safely carry is thus essential to the proper selection of railway motors for specific service.

The necessity for a simple test by means of which engineers in charge of railway systems can determine the loads on motors, and whether these loads are within the capacity of the motor or not, is obvious.

The predetermination of the exact temperature rise of the different parts of a railway motor, operating at given loads and under any given service conditions, is a difficult and complex problem. So difficult and so complex indeed is this problem, that it is impracticable, if not impossible, for manufacturers of railway motors to furnish, for general circulation and in a form which can be readily understood and used by the average engineer, the data necessary for its solution for each type of their product. For general use, however, such detail is unnecessary. The problem, from the standpoint of the user is, as a rule, not what will be the temperature of the field, or of the armature of such a motor under certain service conditions, but rather will the temperature of the motor be such as to insure normal life and reasonable repairs. In other words are the loads carried by the motor within its capacity. Information leading to the solution of this problem can readily be furnished, in brief form, easily understood, readily used, and generally applicable either to the predetermination. or to the final confirmation, of the fitness of a motor for its work.

SERVICE LOADS.

The daily operation of a car over any particular line or route consists of short runs between various intermediate points along the road. These runs may vary considerably in character; some may be up grade, others down grade; some may be short, others may be long; some may be made at slow speed and others at a higher speed, and runs between the same two consecutive stopping points may on different trips be made in different ways.

For any given type of car on a given road the average all-day load, day in and day out, will be remarkably uniform, especially in view of the large number of circumstances which might cause variance. In any given case an average run between stops; that is, an average cycle of operation, can usually be picked out, which will in general fairly approximate the entire service.

Such an average run for a car of the type ordinarily used in combined city and suburban service, is shown in Fig. 1 and for a car in high-speed interurban service, in Fig. 2. In city service alone, the curves would be similar to those of Fig. 1, except that power would be cut off sooner and the length of run would be shorter. Each of these figures shows a complete operating cycle, including the speed, line voltage and current consumption of the car, as well as the current used by each motor and the voltage at its terminals. The current used by each motor is not merely one half of that used by the car, since, when the motors are in series, the car current and the motor current are identical. Both figures are actual cases taken from tests.

It will be seen from Fig. 1 that the load carried by each motor varies from a maximum input of 95 amperes (or about four thirds of the one hour rating of the motor) to 23 amperes (or about one third of this rating). The voltage at the terminals of each motor varies from 80 volts to the rated voltage of 500. Moreover, the load varies through this entire range in less than three fourths of a minute. For the next one fourth of a minute, approximately, while the car is coasting and being stopped, the motors carry no load at all and this entire cycle is repeated a little less often than once every minute.

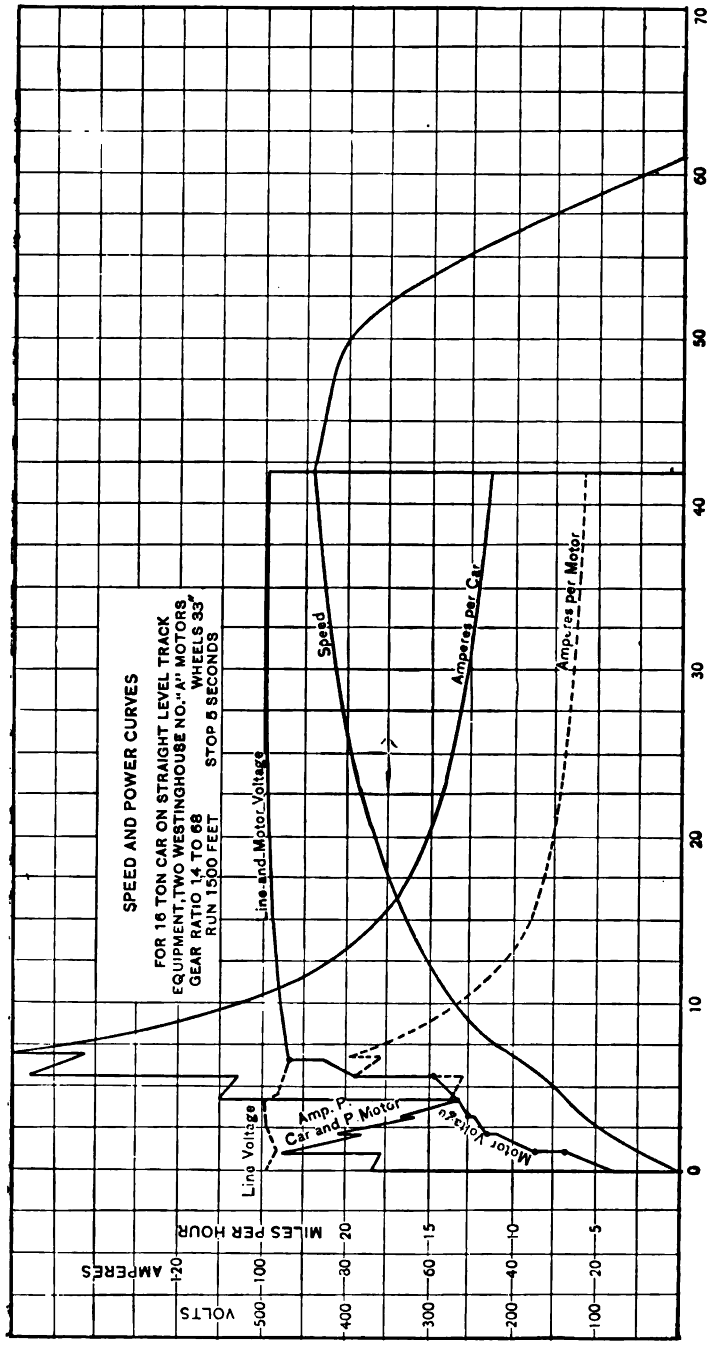

SPEED AND POWER CURVES
FOR 16 TON CAR ON STRAIGHT LEVEL TRACK
EQUIPMENT, TWO WESTINGHOUSE NO. "A" MOTORS
GEAR RATIO 14 TO 68 WHEELS 33"
RUN 1500 FEET STOP 5 SECONDS
Line-and-Motor Voltage
Speed
Amperes per Car
Amperes per Motor
Line Voltage
Amp. P. Car and P. Motor
Motor Voltage
MILES PER HOUR
AMPERES
VOLTS
5
10
15
20
20
40
60
80
100
120
100
200
300
400
500
SECONDS
0
10
20
30
40
50
60
70

FIG. 1.

In the service shown by Fig. 2, the conditions are more uniform. The maximum current is 280 amperes per motor and the minimum, 77½ amperes. The motor voltage varies from 30 volts to 545 volts. For over half of the entire cycle, however, the current and voltage are quite uniform. The length of the cycle in this case is six minutes and twenty seconds. This is considerably longer than the average cycle on most interurban roads.

LOSSES.

When a motor is carrying any load, certain copper and iron losses take place in it, which depend upon the load. It is these losses, which appear as heat, that tend to raise the temperature of the windings. Thus a loss of three watts (neglecting radiation) will raise the temperature of one pound of copper approximately 1° C. per minute, or of one pound of iron approximately .8° C. per minute. The copper loss depends upon the current only, and is proportional to its square, but the iron or core loss depends upon both the current and the voltage and does not follow any simple law. The iron loss in the motors in question, when carrying any given current at any given voltage, is shown in Figs. 3 and 4. Its dependence on both current and voltage may be seen in Fig. 3, from the fact that 20 amperes at 500 volts, produces the same loss as 105 amperes at 305 volts.

The losses which take place in each motor at every instant during the cycle shown in Fig. 1, were calculated from Fig. 3 and from the resistance of the motor and are shown in Fig. 5. Those which occur in each motor in Fig. 2 were calculated in like manner and are shown in Fig. 6. Owing to the great mass of metal in its frame, a motor has a considerable amount of heat-storage capacity. Instead of only a few hundred pounds of copper in the windings to be acted on, the temperature of the frame must also be raised; when cooling the entire mass must cool off simultaneously. That is, when the temperature of the windings is rising, that of the frame must also rise, and similarly when falling. The actual temperatures of the different parts may, of course, be widely different. Owing to this action, the temperature of the windings of the motor does not fluctuate in accordance with the instantaneous losses but rises at a fairly uniform rate depending on their average value.

EQUIVALENT LOADS

The important factor as regards the effect of the service loads on the motors, provided that the maximum loads are within the

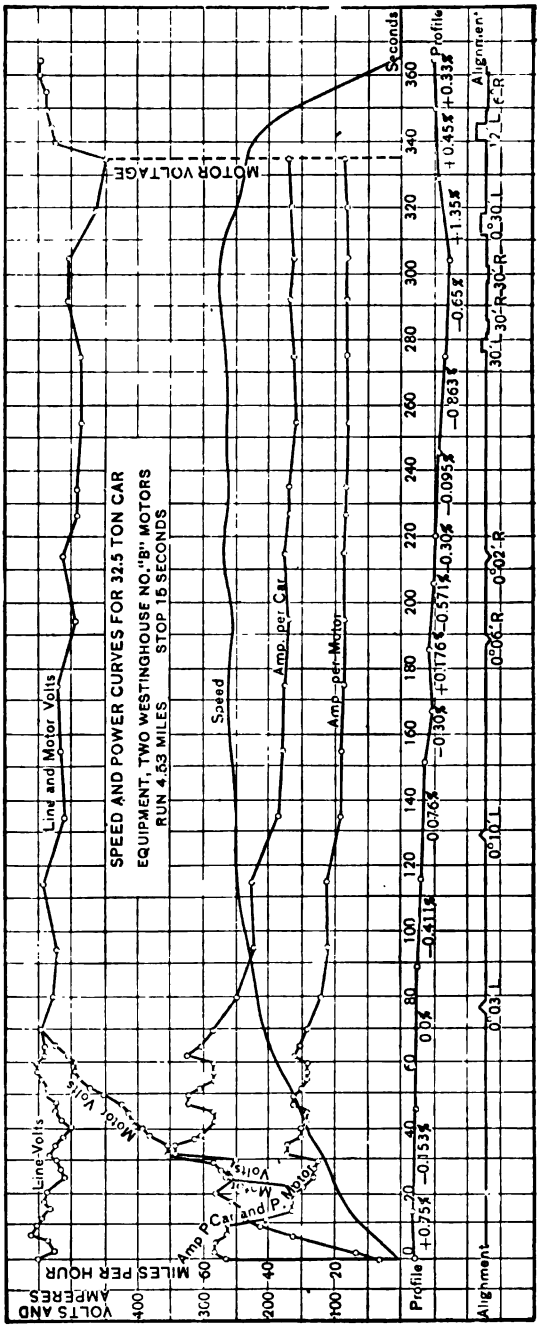

SPEED AND POWER CURVES FOR 32.5 TON CAR
EQUIPMENT, TWO WESTINGHOUSE NO. "B" MOTORS
RUN 4.53 MILES. STOP 15 SECONDS
Line and Motor Volts
Line-Volts
Motor Volts
MOTOR VOLTAGE
Speed
Amp. per Car
Amp. per Motor
Amp. P. Car and P. Motor
Volts
VOLTS AND AMPERES
MILES PER HOUR
400
300
200
100
60
40
20
Seconds
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
Profile
+0.75%
-0.153%
0.0%
-0.411%
-0.076%
-0.130%
+0.176%
-0.571%
-0.30%
-0.095%
-0.863%
-0.65%
+1.35%
+0.45%
+0.33%
Alignment
0°03' L
0°10' L
0°06' R
0°02' R
30' L
30' R
30' R
0°30' L
12' L
6' R

Fig. 2.

proper limits, is thus the average value of the losses, averaged of course over the entire time of the cycle; that is, in Fig. 1 for 66 seconds and in Fig. 2 for 380 seconds. It is evident that the average copper loss in any case is equal to that which would be produced by the continuous application of a current equal in value to the

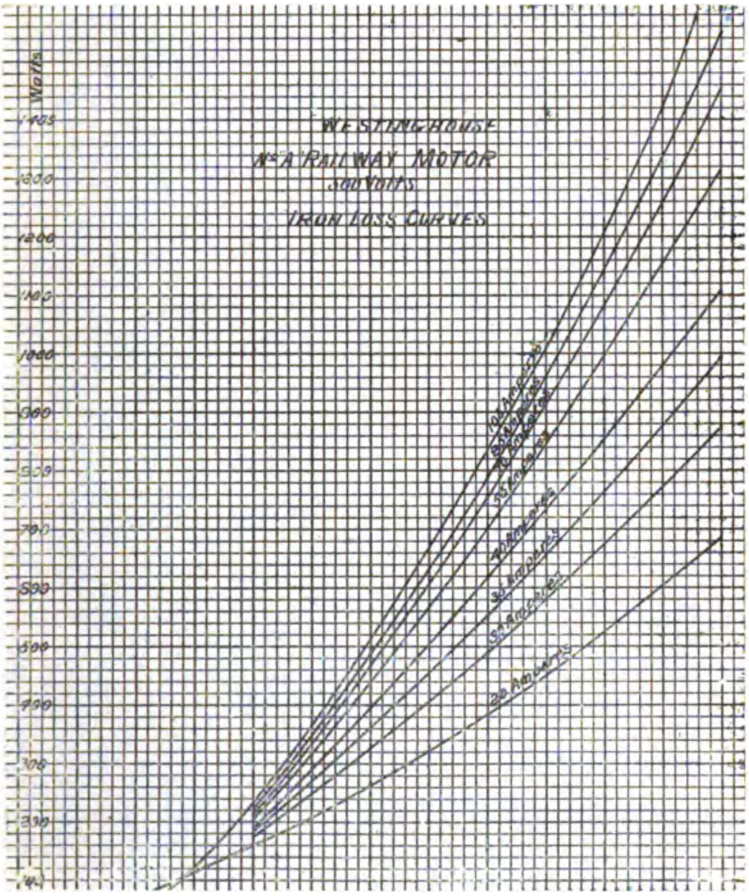


FIG. 3.

root mean square of the service currents. For instance, in Fig. 5 the average copper loss is 750 watts. The root mean square current per motor is 34 amperes and the resistance .65 ohms, which of course gives the same result. Thus the variable service currents shown in Fig. 1 are equivalent—with regard to the heating effect of the copper loss produced by them—to a current of 34 amperes per motor, applied continuously.

The average iron loss produced by the service loads of Fg. 1, as noted in Fig. 5, is 400 watts. Referring to Fig. 3 it will be seen that a current of 34 amperes, *i.e.*, the root mean square current, applied to each motor at 325 volts will produce this same iron loss. Thus, if this current and voltage is applied to the motor for the entire cycle, the average losses in the motors—

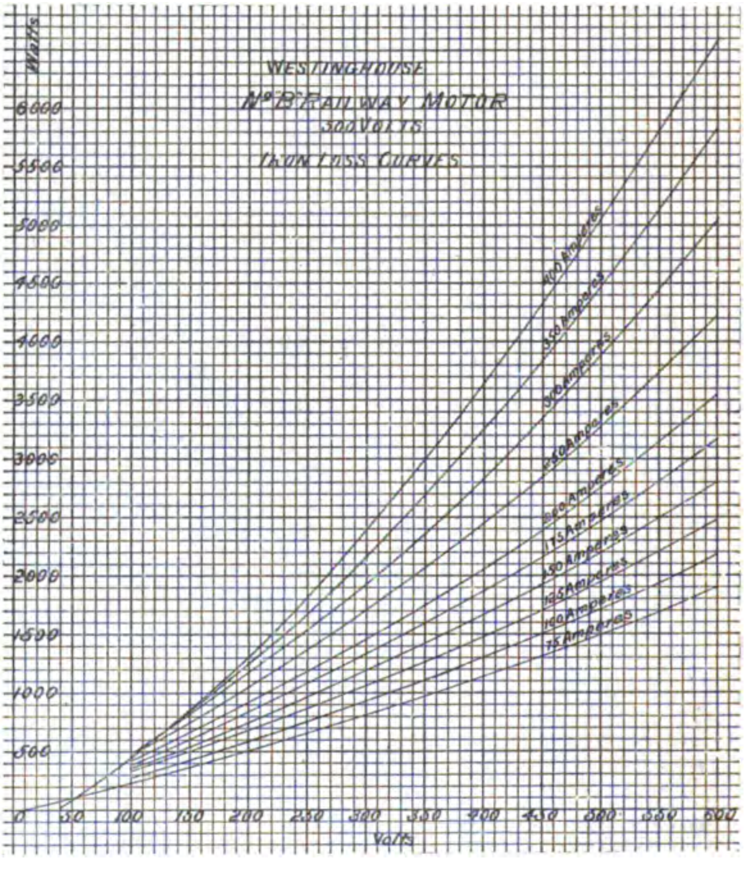


FIG. 4.

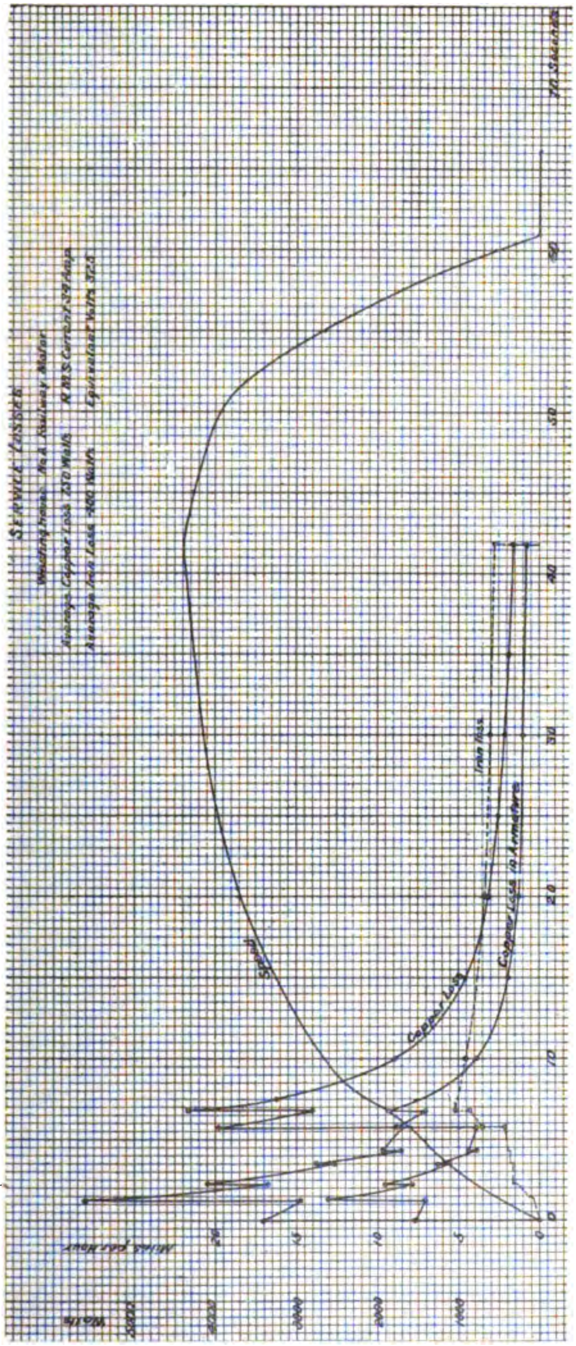

SERVICE LOSSES
Westinghouse No. 4 Railway Motor
Average Copper Loss 730 Watts
R.M.S. Current 39 Amp.
Average Iron Loss 300 Watts
Equivalent Volts 325
Speed
Copper Loss
Iron Loss
Copper Loss in Armature
Miles per Hour
Watts
0
5
10
15
20
25
1000
2000
3000
4000
5000
10
20
30
40
50
60
70 Seconds

FIG. 5.

both copper loss and iron loss—will have the same value and the same distribution as the losses due to the service loads. This voltage may be called the " equivalent " voltage of the service. In the service shown in Fig. 2, the relative values of the losses are somewhat different. In this case the average copper loss is only 960 watts while the average iron loss is 1410 watts. The root mean square current is 107 amperes, and referring to Fig. 4 it will be seen that the equivalent voltage is 420. As regards the production of heat in the motors, then, the service shown in Fig. 1 may be described as equivalent to a continuous current of 31 amperes at 325 volts, and that shown in Fig. 2 as equivalent to 107 amperes at 420 volts. Any railway service may be similarly described.

This method of equating the service loads on a railway motor to simple and intelligible terms was devised by Mr. N. W. Storer of Pittsburg, and gives a convenient way of expressing the service capacity of railway motors in a usable manner.

The limiting capacity of any type of motor may be readily expressed by the manufacturer in terms of the current (root mean square) which it will carry continuously at various voltages (equivalent voltage) with a safe rise in temperature. In choosing a motor for a given service, the root mean square current and equivalent voltage can be calculated from the speed-time curves and a comparison of these results with the values allowable for the motor in question will determine its fitness. Where motors are already installed, the continuous equivalent of the service can be found by means of comparatively simple tests and the relation of the actual loads carried by the motors to their safe capacity, thus determined.

It has doubtless been noted that the equivalent voltages in the widely different service shown by Fig. 1 and Fig. 2 differ by less than 100 volts. If the run in Fig. 1 had been shorter, the equivalent voltage would have been somewhat lower, and if that in Fig. 2 had been longer (it is already longer than the average for perhaps nine tenths of the interubran roads now in operation) the equivalent voltage in it would probably have been somewhat greater. It has been found that where the equivalent voltage is less than 300, a reduction of voltage, with the same current, makes but little difference in the temperature attained. Even when the equivalent voltage is changed from 300 to 400 volts only a comparatively slight reduction in current is necessary in order to

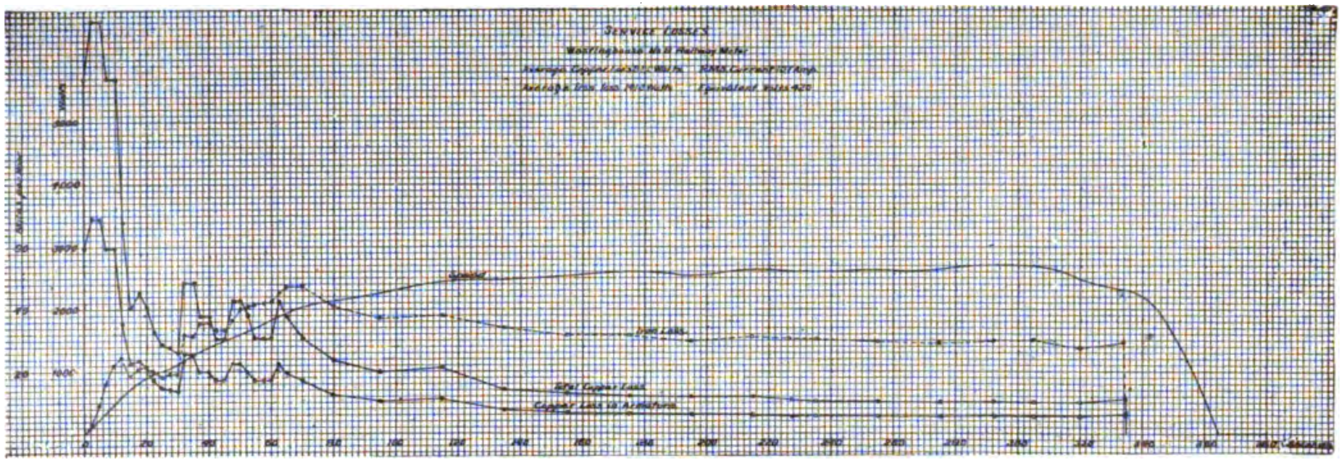

Service Losses
Iron Loss
Total Copper Loss
Copper Loss in Armature
100
120
140
160
180
200
220

FIG. 6.

maintain the same temperature rise. Thus the capacity need be stated at only one or two different voltages.

In many cases where tests or calculations are made to determine the approximate service loads on a motor, the average voltage at the motor terminals is a sufficient indication of the iron losses and the equivalent voltage need not be determined. In Fig. 2, for instance, the average voltage at the motor terminals is 418, which is very close to the equivalent voltage. In Fig. 1 the average motor voltage is 290 volts, which is about 90 per cent. of the equivalent voltage; but it has already been pointed out that when the equivalent voltage is as low as this, any further reduction has but little effect on the temperature.

An ammeter in the circuit of one motor and a voltmeter at the terminals of the same motor, read at suitable intervals during a typical round trip over a given route, will thus give sufficient data for determining the loads which a motor is carrying in service. From the current readings, the root mean square current can be found and from the voltage readings, the average, or the equivalent voltage. It will be seen from Figs. 5 and 6 that the starting current is a most important factor in determining the copper loss, hence it is essential to get an accurate idea of this. On account of the rapid variations of the current while the car is starting and the short duration of the starting currents, it will be seen from Figs. 1 and 2 that readings should be taken at very close intervals, preferably at intervals of five seconds, or less, in order that the large currents used in starting may be duly represented in the results

Part II.

TESTS ON AN ELECTRIC CAR IN CITY SERVICE.

The foregoing part of this paper has been devoted to a discussion of the average loads carried by railway motors in service and to methods of determining them, with a view to preventing the application of such motors to work for which they are not suitable. In the following, the results of a comprehensive series of tests on a car in exceptionally severe city service are presented, showing the actual variation of the loads in all-day service. In these tests the temperature of the field coils of one of the motors was measured in addition to the average loads and the general relation between average load and temperature may be seen. Complete details in regard to schedule speed, passengers carried, number and duration of stops, etc., were taken also and the tests afford data on a number of minor subjects which have a bearing on the choice of motors for city service.

The tests in which these results were obtained were made recently, under the direction of the writer, on a car of the Pittsburg Railways Company. The car was of the single-truck type, approximately 30 feet long over all. The body was 20 feet long and had longitudinal seats for 28 people. The equipment consisted of two Westinghouse No. 62 motors with electric brakes of the disc type. The weight of the empty car complete with equipment but without load was approximately 12 tons. The motors were geared for a maximum speed on the level of approximately 26 m.p.h with 500 volts. The car was run in regular service, carrying passengers. Three observers were needed to take the necessary data. Two of these were located on the front platform with the motorman and the third on the rear platform with the conductor. The primary object of the tests was to study the temperature attained by the motors in all day service (particularly the temperature of the field coils). A complete record of all conditions was kept and from this a number of other interesting facts were obtained in addition to the temperature results.

METHODS OF MEASUREMENT.

It was desired to measure the temperature at frequent intervals, so that this necessarily had to be done without interfering with the operation of the car. The ordinary methods of temperature measurement by thermometer or by increase of resistance of the windings of the motor could thus not be used. The following plan was adopted. A small temperature coil consisting of 48 feet of No. 27 annealed iron wire was calibrated in an oil bath and an accurate comparison between its resistance and the temperature was obtained. This iron wire was then wound upon two thin wooden strips, and during the process of winding a field coil for use on one of the motors these two strips were placed in the interior of the coil, one on each side, about half-way between the center and the outside. Leads were brought out from this iron wire coil and measurements of its resistance which could thus be taken, gave the temperature of the interior of the field coil. The field coil which had been prepared in this way was placed on one of the motors of the car and the leads from the temperature coil brought to a portable Wheatstone bridge on the front platform. By the use of this arrangement the temperature of the coils could be obtained at any time whether the car was running or standing still and whether the motors were using current or not. During the tests, measurements were made every four or five minutes. Before the field coil was placed on the motor, a test was made on it to determine the relation between the temperature as indicated by it and the resistance of the field. To obtain the temperature of the armature it was proposed to measure its resistance during the short lay-over at the end of each round trip made by the car. The lay-over was so short, however, that this could be done only hurriedly, and frequently could not be done at all. In general, the results were not very satisfactory. As far as could be judged, however, the temperature of the armature was not materially different from that of the field.

In connection with the temperature of the field coil, it was desired to note the root mean square current producing this temperature. In order to avoid the great amount of labor which would have been necessary to calculate this quantity from the current for an entire day's run of nineteen or twenty hours, it was measured directly, as follows:

A street-car wattmeter was connected in the field circuit of the motor so that it would measure the watthours lost in the field. In adapting the wattmeter for this purpose the large resistance which is ordinarily inserted in series with the armature of the meter when it is used on a 500-volt circuit was replaced by a smaller resistance suitable for the voltage drop across the field, with maximum current. The wattmeter was of course calibrated with this special resistance. When arranged in this way, the wattmeter measured the product of $I^2 R$ and T, where I is the current, R the resistance of the field coils and T the total time. The resistance of the iron wire temperature coil at any time, by reference to the comparative test previously made, showed the resistance of the field coil, and the average value of this resistance between any two times could thus easily be found. The time was noted with a watch and hence T and R could be eliminated from the measurement made by the wattmeter, leaving I^2, the square root of which was the quantity desired. In working up the test, the root mean square current was calculated in this manner for each single trip between terminals and also for each round trip. Previous tests over this same road had showed the average motor voltage to be about 175 volts and in the present tests this quantity was not measured. The average line voltage had been found to be about 450 volts.

The observer on the rear platform noted the number, duration and location of stops made by the car, the time of passing prominent points along the route and also the entrance or exit of each passenger.

TEMPERATURE RESULTS.

The results of the temperature tests are shown by the curves in Figs. 7 and 8. These curves show also the root mean square current, the number of stops and the maximum and average number of passengers for each single trip. Five different runs were made with the car equipped as above, three over the Hamilton Avenue line (42,000 feet long, one way) and two over the Highland Avenue line (36,000 feet long, one way). For the first 25,000 feet, these two lines coincide. On the Hamilton Avenue line the car was run singly. On the Highland Avenue line a trailer was hauled for one trip in the morning and one trip in the afternoon. Fig. 7 shows the results of one of the tests on the Hamilton Avenue line and Fig. 8 of one on the Highland Avenue line.

Referring to Fig. 7, it will be seen that, starting at a temperature of 25½° C., or 13° C. above the temperature of the air, the temperature of the inside of the field coil rose gradually until at the end of eight hours it had reached a temperature of 74° C. During the next eight hours the temperature remained practically constant at this value (maximum rise, 64½° C.). During the following three hours, which were late in the evening, the air temperature decreased and the temperature of the field coil decreased with it, reaching a temperature of 70° C. at the end of the last regular trip. Measurements of the temperature were taken also at intervals of ten minutes while the car was standing idle during the night and these results are likewise shown in Fig. 7. The cooling of the motor was interrupted for a short time by the application of current in order to move the car from the yard into the car barn, and a hump in the curve shows the effect of this. It will be seen that after approximately four hours of idleness, at the end of which time the car was made ready to start out on the next day's service, the temperature had fallen from 70° C. to 32 °C., the latter point being a little over 20° above the temperature of the air. Thus ordinarily a motor never gets completely " cold." The curves shown in Fig. 7 were taken on the first day of a two days' continuous test. On the second day the curves obtained were practically duplicates of those shown.

On the run on Highland Avenue, Fig. 8, the temperature of the field coil at starting was 18° C. or 5° above the atmosphere. The addition of the trailer for its morning trip caused a much more rapid rise of the temperature than was the case in the run shown in Fig. 7 and a temperature of 60° C. was reached at the end of about three hours. After the removal of the trailer, the rise in temperature was more gradual. Had it not been for the addition of the trailer for its evening trip, the temperature of the field coil in this case would have remained constant at approximately 75°C. giving a rise approximately the same as in the other case. The addition of the trailer, however, caused a rapid rise to a temperature of 98½° C. When the trailer was again removed and the motor run once more at its normal rate, the temperature fell off gradually to 74° C.; that is, a little less than its former temperature. It should be noted that the trailer was on for this afternoon trip only 1½ hours, while about 3 hours were required after its removal for the motors to cool off to the temperature at which they were before the addition of the trailer, and at which they would probably have remained had the trailer not been added. If the trailer had been left on for additional trips, it is evident that the temperature would have reached a much higher value. As the car was not put in service for an early run on the day following this test, the cooling curves could be continued for a longer time. It will be noted that the field coil cooled from a temperature of 71½° C. to a temperature of 25° C. (which latter point was a little over 12° C. above the atmosphere) in about 8 hours.

LOAD ON MOTORS—ROOT MEAN SQUARE CURRENT.

Referring to the root mean square current values shown on Fig. 7, it will be seen that these vary for a single trip, alternating in direction, from 39 to 51 amperes, or a little over 25 per cent. It will be seen that the values for the different up-trips, however, and those for the different down-trips are much closer together in each case than this. Comparing the root mean square currents on a basis of round trips instead of single trips, the variation for the different round trips on this all day run was only 42.5 amperes to 46 amperes, or less than 10 per cent. The average value of the root mean square current for the entire day's service was 43.6 amperes, so that the difference between this average and the extremes for the various round trips was very slight. The average all day values of the root mean square current for five different all-day runs, made on two different lines and made, respectively, on the 9th, 10th, 16th, 21st and 24th day of the month, vary from 39.8 amperes to 46.6 amperes. This is quite a remarkable uniformity.

It will be noted from Fig. 8 that the effect of the two round trips with the trailer changed the all-day average root mean square current only from 43.6 to 45.8 amperes. During the trips when the trailer was hauled, however, the load was quite large and it will be seen that the difference both in the maximum and in the average temperature, caused by the addition of the trailer, was considerable. It will be evident from this that in selecting motors, or in determining the loads carried by them, any special service involving the carrying of extra loads for any length of time should be considered separately whenever the length of time has anything greater than a momentary value.

The two lines on which the tests were made, naturally divide themselves into three sections. The first of these is a loop in the down-town or business portion of the city about a mile in length where the car is run very slowly and makes frequent stops. On this portion of the road there is great congestion due to the large number of cars and the movement of any given car over this portion of the route is largely a succession of jerks. The second division is from the end of this loop (High St., see Fig. 9), to Atwood St. This portion contains several long, heavy grades, the most important of which, 2½ per cent. for 3500 feet and 4 per cent. for 3000 feet, are in the same direction. Comparatively few stops are made on this section. The third portion of the road is from Atwood St. to the outer terminus of the line. On this part of each line the grades are lighter and occur alternately up and down in shorter lengths. There are also few obstructions and a high speed is made. The time required on the first two portions of the road is about the same as that required on the third portion. In order to estimate the relative severity of the service on these different sections, the root mean square current was calculated for a number of round trips over each. The average for these trips was 40.5 amperes for the first section, 41.8 amperes for the second section and 45.6 amperes for the third section. The speeds which are made on these different sections may be seen from the paragraph under that heading. These results are particularly interesting as showing that although the average root mean square current for the trips *up* the heavy grades was 50 amperes, the average for the *round trips* over this section was not materially different from that on the remaining sections and was even less than that on the third section, where the track is most nearly level.

SCHEDULE SPEED.

The length of the route over the Hamilton Avenue line is 8½ miles. The running time was in general about 95 minutes for the round trip, making a schedule speed of 10.7 m.p.h. On the Highland Avenue line the distance is 7⅓ miles and the running time for the round trip was 76 minutes. The schedule speed on this line was thus 11½ m.p.h. In the down-town section of the city about 14 minutes is required to traverse a loop 5500 feet in length. The schedule speed over this distance is thus approximately 4½ m.p.h. Over the second section of the road, between High St. and Atwood St., the distance is 11,000 feet and the schedule speed approximately 11 m.p.h. Over the third section, the schedule speed on the Hamilton Avenue line was 11.6 m.p.h., and on the Highland Avenue line 12.35 m.p.h.

STOPS.

Figs. 7 and 8 show the number of stops for each trip during those runs. The average number of passenger stops per round trip on each of the different routes was calculated and showed a value between 4 and 5 stops per mile. It is estimated that the practical stops required at curves and crossings, in addition to the stops for passengers, would make the total number of stops about 6 per mile. The length of stops varied from zero seconds, that is, a mere slow-down, up to about 15 seconds. The average duration of stop for the run shown in Fig. 7 was 4 seconds.

PASSENGERS.

The maximum and average passenger loads for each trip of the respective all-day runs are given on Figs. 7 and 8. The net passenger load was calculated each time a passenger entered or left the car and these net loads were averaged. The average loads given in Figs. 7 and 8 were thus figured without any reference to the distance which the passengers were carried. For the run in Fig. 7 the net passenger load on each trip was plotted, with the distance as a basis, and the average loads were figured also from these curves with reference to the distance travelled as well as to the number of passengers. The results found in this way, however, differ only very slightly from those calculated on the other basis. Fig. 9 shows these passenger loads for the various up trips. The curves for the down trips are in general similar to the reversal of these curves. It will be noted that on this line most of the passengers have to be carried over a considerable portion of

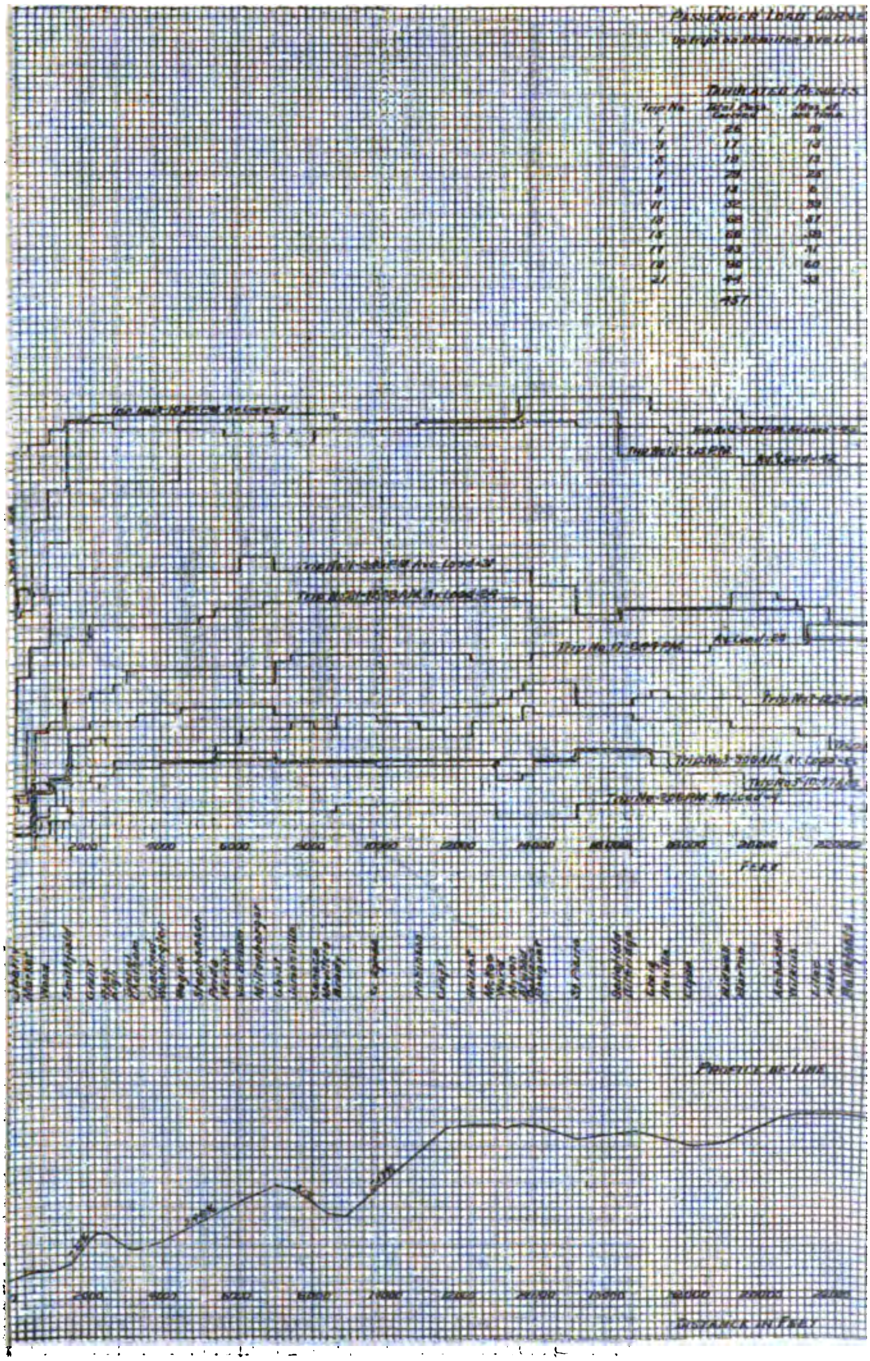
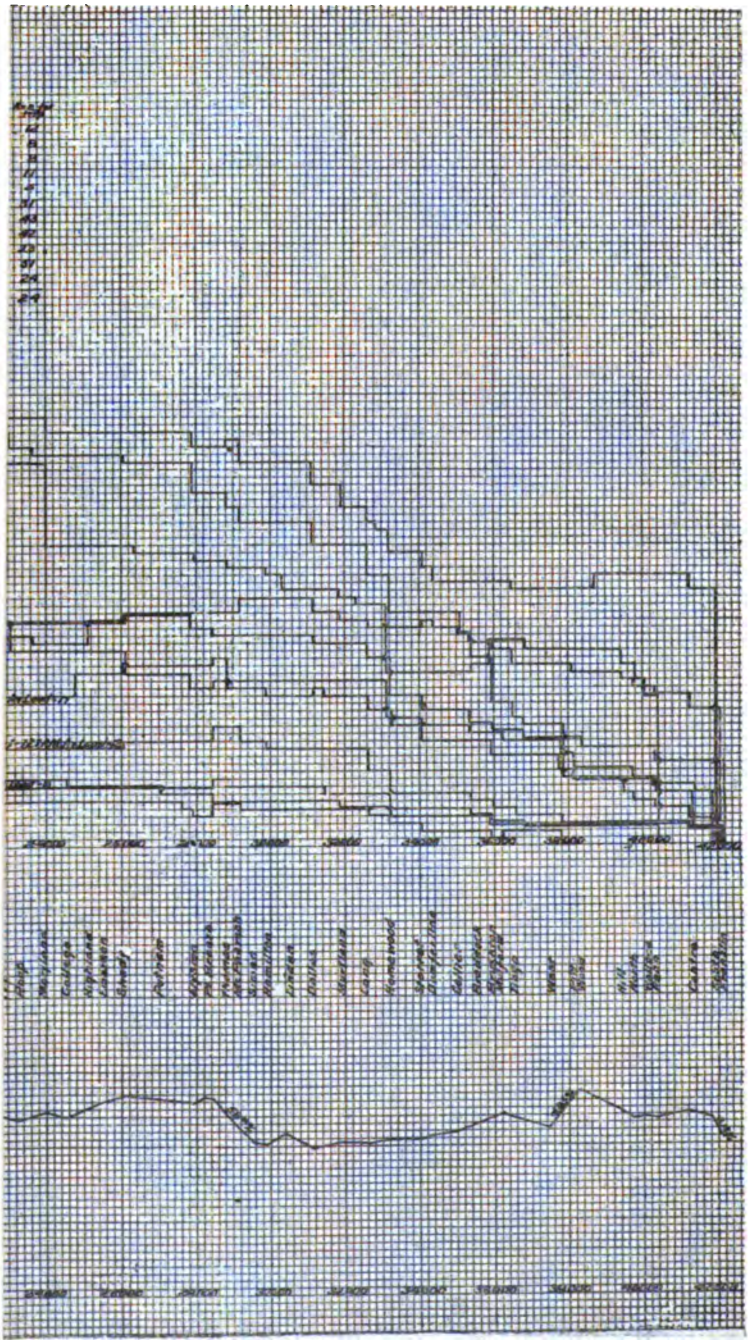


FIG. 9 —(Renshaw



the route. The car loads while passing over a very short distance, carries almost the entire load about six tenths of the length of the route and then discharges it gradually. It will be seen from Fig. 9 that the car carried 457 people during the day on the outbound trips. The number carried on the inbound trips was 499, making a total of 956 in 18¼ hours, or 52½ per hour. The average load, as calculated from Fig. 9 and the corresponding curve for the other direction, was 24 passengers, or six sevenths of the seating capacity of the car.

In presenting Part I. of this paper, novelty and originality is claimed only for the treatment of the ideas, not for the ideas themselves. By using as illustrations the results of actual tests rather than of calculations and by separating the matter entirely from any discussion as to how the allowable loads for motors should be determined, it has been sought to bring out the simplicity, accuracy, and general utility of this method of equating service loads. It is further desired to emphasize the fact, already pointed out, that it is the common tendency, even at the present time, to select motors which are too small and that a simple method of determining the fundamental questions—what the service loads on a railway motor are in an actual case, or what they will be in a proposed case, and whether these loads are within the capacity of a given motor or not—has a wide field of usefulness which a more elaborate method would be unable to reach.

Part II. has been included not only for the sake of the results shown, which in themselves are interesting and instructive, but also to illustrate the methods employed. Particular attention is called to the method of measuring the watts lost in the field of a motor by means of a railway-type wattmeter and of deducing the value of the root mean square current from this. Under ordinary circumstances, where it is desired to use this method, the resistance of the field coils at the beginning and end of the test could be measured by means of the current and voltage drop, or in any other convenient way. The method is a simple and convenient one and used with care will give results not materially less accurate than measurements of power made by a similar instrument.

The writer is indebted to the Westinghouse Electric and Manufacturing Company for the various curves and results upon which the paper is based.

DISCUSSION.

DR. CARY T. HUTCHINSON:—In a paper presented to the INSTITUTE January 24, 1902, I described a method for determining the motor capacity and energy used for any schedule. Since that time I have extended the scope of this method and have made it to include the predetermination of the temperature rise of a motor when operating on any schedule, knowing the heating constants of the motor to be used.

In the first paper the datum point for these motor curves was the load determined by the " hour rating." That is, the load the motor will carry for one hour with a temperature rise of 75°C. when tested on the stand; these limitations made the results given in the first paper seem applicable only in special cases. I have now broadened the treatment so that the datum point may be considered the input that the engineer chooses to assume for the motor when operating at full speed with resistance cut; that is, the maximum power input for the run. This may be the commutation limit of the motor, or some definite proportion of it, as 75 per cent. This generalization is justified by the fact that the speed curve is very nearly a rectangular hyperbola and consequently the ordinates are in inverse proportion to the abscissæ.

By reason of this independence of the shape of the speed curve of the relative point on the motor characteristic assumed for the datum, any value may be assigned to the power that a particular motor may deliver during initial acceleration; that is, any power up to the commutation limit; it may be assumed to be less than equal to or greater than the power denoted by the hour rating, but whatever value is adopted, the motor capacity as limited by commutation is thereby fixed, since the results are expressed in terms of that input denoted by the datum point. Therefore it only remains to determine the conditions under which the motor must be used to attain the limiting temperature elevation, while at the same time not going over the limit of input determined by commutation or by the judgment of the engineer. I believe the hour rating for the input during this period is not unduly conservative; it leaves a margin for greater power on curves, grades and for emergencies.

In my first paper, I assumed that a tramway motor will, on an average, carry a heat loss of 3 per cent. of its hour load, with a temperature elevation of 75° Centigrade. This was a fair average figure and claimed to be no more. But individual motors differ materially in their heating characteristics, hence I have elaborated the method so that it may be used for motors having any I^2 R loss and any core loss, and making any schedule under any initial acceleration.

I have considered the I^2R losses and core separately, and have determined for each the ratio of average loss to loss at rated load, for the several initial accelerations; having the ratio of average loss during acceleration to loss at rated load, the actual average losses for any motor are found by selecting the proper value of the ratio and multiplying it by the loss at rated load—this being done separately for copper and core losses; the results added will give the average loss during acceleration.

The temperature elevation of the parts of a motor, as determined by tests, depends materially upon the ratio of the distribution of the total heat loss between the armature and field; hence this ratio of distribution must be determined for the several initial accelerations.

Thus I get the average loss during acceleration and its distribution; to get the average loss during the run, it is necessary to determine the ratio of time of acceleration to time of run for the various initial accelerations, and for all values of the through acceleration.

Knowing then the average loss during the run and its distribution between armature and field, the temperature elevation of the motor can be determined by comparing this average loss with the temperature rise per watt lost, as determined by tests made under service conditions giving the same ratio of distribution of losses.

The time is so short that I am able only to refer to these results here; later, I hope to present the matter in detail to the INSTITUTE.

GOLDSBOROUGH PAPER DISCUSSION.

MR H. G. STOTT:—In regard to Professor Goldsborough's paper on storage-battery in sub-stations, I have been looking over the load carried by the rotaries and find that the maximum in any substation is 68 per cent. overload for a few minutes. As a rotary can safely carry over 200 per cent. load for several minutes, it is apparent that storage batteries are entirely unnecessary as far as substations are concerned. I think it would be very interesting if a test had been made; first, running for one week without the batteries; secondly, running the next week with the batteries, determining the efficiency at the power house during each period. I would like to ask Professor Goldsborough if such a test has been made. If the engine had been properly designed for the work they would certainly show better economy without the battery than with it.

PROFESSOR GOLDSBOROUGH:—We attempted to cut the storage-batteries out of service in some of the substations, but found that doing so was rather disastrous to the efficient operation of the generating equipments at the main station, and the engineers in charge hardly felt like subjecting the generating equipments to the strain. There is a very important point though, in connection with all of this work, which I hoped to be able to develop in connection with the storage-battery paper, to determine the efficiency of the whole system, with the best possible adjustment of the storage-batteries, as compared with its efficiency without this adjustment

Although we had the data for making the necessary calculations for this comparison, we were unable to do so through lack of time.

DISCUSSION OF GOLDSBOROUGH AND FANSLER PAPER.

[COMMUNICATED AFTER ADJOURNMENT BY MR. A. H. ARMSTRONG.]

This admirable paper started out with a statement to the effect that it would furnish a clew to prospective purchasers whether or not the storage-battery should be used in substations and what capacity this battery should bear to the substation installation. This question has bothered a good many of us from time to time, and I was very much disappointed, on proceeding further, to find that the main question has been overlooked and the paper was devoted to a series of detailed tests which are interesting, but which do not consider the economical value of the battery in the station. If the tests had been carried out somewhat more elaborately, had included coal consumption in the generating station with and without the storage-battery, had entered into the first cost of the storage-battery and the rotary converter which it replaced, with the interest on the increased cost together with the cost of maintaining the battery in operation, it would have furnished some guidance for the consulting engineer in similar installations.

Many of our suburban roads are commencing to appreciate the effect which frequent stops and breakdowns have upon their patronage. Such roads are using protective devices of all kinds, installing expensive automatic switches, providing duplicate pole lines, and in every way endeavoring to ensure continuity of service. To engineers of such roads the storage-battery appeals as a further protective device against breakdown. Most of the troubles in suburban roads result from defective insulators, or other shut-downs to which their long-distance transmission lines expose them. Some of these railway systems are tied up to transmission lines of over 100 miles in length, and although this transmission line is divided up into sections, may be duplicated, or may form part of a ring system, it is evident that there is the danger of occasional shut-down, more especially when the system is new. The office of the storage-battery in the substation therefore cannot be considered alone from the economic standpoint of saving in coal, etc., but from the operative point of view as a safeguard against breakdown. A battery installed in a substation and having capacity enough to run the normal service for say three or four hours will afford an assurance of constant running possessed by no other device. Oftentimes its installation can be advocated by the conservative engineer when from the dollars and cents point of view it shows up on the wrong side of the balance sheet.

I would regard this point of view of the storage-battery in the substation as the proper one, as it is very difficult to show any economy in operating expenses by the use of the storage-battery unless coal is abnormally high and storage-batteries abnormally cheap.

DISCUSSION OF RENSHAW PAPER.

[COMMUNICATED AFTER ADJOURNMENT BY MR. A. H. ARMSTRONG.]

Mr. Renshaw has given us the analysis of a series of service runs on railway motors which is a step in the right direction. There is too little experimental material obtained and too little regard paid to the proper selection of this type of apparatus, which has a value exceeding that of the generators and rotary converters feeding into them. As this paper was, however, presented probably for the information of consulting engineers and not designing engineers, I do not see the use of the term " square root of the mean square current per motor." While this value was very carefully and probably accurately obtained, it was put to no practical use, that is from the consulting engineer's standpoint. An engineer has to face the problem of selecting a motor to do a certain piece of work. He is the best judge of the conditions under which the motor will operate in a prospective system and needs the material at hand by means of which he can select, according to his best judgment of temperature rise and money expended, the proper equipment for the case in hand. After reading Mr. Renshaw's paper he will become imbued with the idea that the proper thing to do is to obtain the square root of the mean square current of an equipment operating over the profile of his route under service conditions. Unfortunately, however, there is no direct connection between this square root of the mean square current and the heating of the equipment to be chosen. Having obtained the square root of the mean square current, it will, it is true, furnish the basis of calculating the copper losses of motor, provided its resistances are known. Were the motor constructed so that it would operate without a core loss, this value would be very valuable and probably give directly, with a factor, the heating of the motor for any class of work. The core loss, however, is so variable in quantity and distribution, and withal forms such a considerable part of the total motor losses that it cannot be ignored in this arbitrary manner. The fact further that the motor may be run upon the stand at the square root of the mean square current and that a voltage giving presumably the proper core loss will also fail to furnish the necessary basis for motor calculations, owing to the difference in ventilation upon the stand and upon the trucks and also due to the fact that the core loss is not distributed properly at the arbitrary stand voltage chosen. The core loss also does not correspond with the average voltage to which the motor is subjected when running, this loss on the contrary being a variable depending upon the particular motor in question and the conditions upon which it is operated in service.

It is unfortunate perhaps that there is no short method yet proposed by which a railway motor can be rated and which will express its relative capacity to do work. The only accurate method known is to follow through the various losses in the motor for a given piece of work, determine experimentally the degrees rise per watt loss, and thus obtain the temperature rise. This method entails an enormous amount of experimenting and calculation, but the results justify the expenditure of labor and time, owing to the fact that railway motors operate at nearly double the temperature of stationary apparatus and hence any considerable inaccuracy may lead to much more serious results in the selection of this type of apparatus. A motor rising 60 or 70 degress C. above the air will reach and oftentimes pass the boiling point of water, and an error of 10 or 20 per cent, may lead to disastrous results. It is just here that the square root of the mean square current fails as a means of determining the proper size of motor for a given service. While it does serve as an indication of the motor's temperature, it is an indication only and leads to no practical results.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 30, 1903.

REVERSE-CURRENT CIRCUIT-BREAKERS AND THE PROTECTION OF TRANSMISSION LINES.

BY LEONARD WILSON.

Engineers who have had the experience of running faulty apparatus in parallel have long recognized the inadequacy of a system of excess-current protection; but the necessity for adopting reverse-current protective devices is still far from being universally recognized. The advantages of reverse-current protection over excess-current protection are briefly: That the former cuts out the faulty apparatus and does so at the moment when only a small current is flowing, thus causing the minimum disturbance to the system, while the latter is very liable to cut out all the healthy units instead of the one faulty one and only operates when the current is excessive. It will be seen, therefore, that wherever current is being fed to a common bus-bar from more than one source, reverse-current circuit-breakers should be installed.

The evolution of the reverse-current circuit-breaker has been a long process, and even at the present day devices are installed which do not possess the necessary characteristics for reliable operation and consequently bring discredit on this system of protection. The following are the more important of the characteristics referred to.

(1) A reverse current equal to 25 per cent. of the normal must be sufficient to operate the breakers.

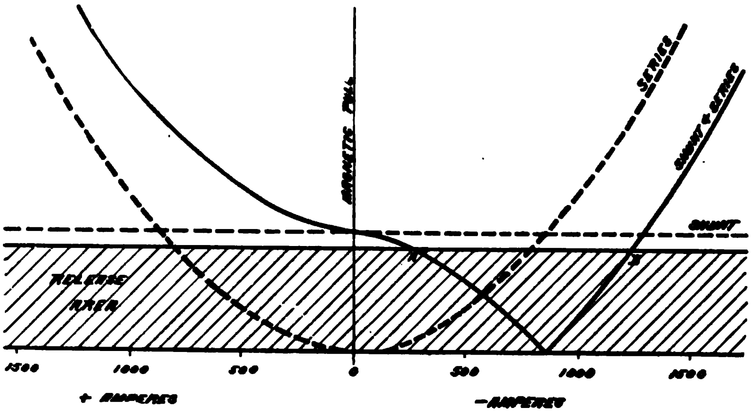
(2) The magnetic pull must continue to increase with an increase of the reverse current, so that any sticking of the mechanical part will merely cause the breaker to operate at a sightly higher current, and that if the reverse current suddenly

attains a very high value the operation of the breaker will be the more certain.

(3) A failure of the potential coil, from whatever cause arising, must not operate the breaker.

(4) The device must in some way continuously indicate whether it is in working order or not.

With regard to the first point, it is important that the device should not be too delicate in its action, and to obtain this, the relay is in some cases provided with a time-element. This, however, does not produce very satisfactory results as it allows the current (when there is a serious fault) to rise to too high a value The best practice seems to be to have quick-acting relays set for a moderate return current, 25 per cent, having been found a very suitable value. If for any reason, a combined reverse and excess-current breaker is required it will be found better to provide two separate tripping-coils, as a combination of the two in one necessitates a certain compromise in the characteristics of the device. A convenient method of illustrating the action of devices of this kind is that of plotting characteristic curves showing the relation between the operating force and the current producing it.



FIG–1

The force that will just operate the device is shown by the boundary of a shaded area, and the part of the curve lying outside this area indicates the range of the current at which the breaker remains closed. Fig. 1 shows the characteristic curves of a circuit-breaker which operates when the magnetic pull falls below a fixed value, and it will be seen that in this type the curve crosses the boundary of the shaded area at two points, A and B. In consequence of this, if the reverse current suddenly attains a value higher than L, the device will fail to operate. Also it will be noted that an interruption of the shunt current will operate the breaker. Fig. 2 shows the curve of a circuit breaker which operates when the magnetic pull, due to the product of the seires and shunt current, exceeds a certain value; and it will be seen that the objectionable features of No. 1 curve are absent from this.

It is unnecessary to describe in detail any particular form of reverse current circuit breaker, as such information is readily obtainable from the bulletins of manufacturing companies, but a short description of a device, novel in this country, together with a demonstration of it in operation, may prove of interest.

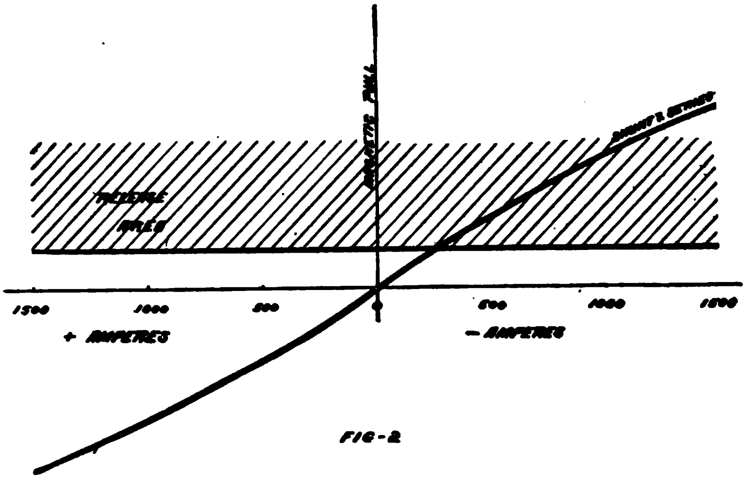


FIG-2

Some operating engineers prefer to trust to the switchboard attendant in case of trouble rather than to install any form of automatic circuit-breaker, but in such cases it is very necessary to have some visual signal to indicate which of a number of generators is the faulty one. For this purpose, some form of wattmeter relay arranged to close a local lamp circuit may be used; but a simpler and more reliable device is the one illustrated in Fig. 3. This device, invented by Mr. L. Andrews, of England, consists of a double magnetic circuit magnetized by shunt and series windings and provided with two secondary windings connected to red and green signal lamps. In the diagram A A is the shunt winding, connected across the station bus-bars and B is the series winding, consisting of one turn of the main cable connecting the generator to the bus-bar. With only the shunt winding excited, the secondary coils C C have each half the normal lamp voltage induced in them, and consequently both red and green lamps glow faintly. When the generator delivers current to the bus-bar, the action of the series winding is to neutralize the flux through one secondary winding and increase it through the other, thus extinguishing the red lamp and lighting up the green one; conversely, when the current reverses, the green lamp goes out and the red one lights up. This device appeals to operating engineers by its simplicity and the complete absence of moving parts. The use of two lamps (preferably each in duplicate) enables the switchboard attendant at any time to ascertain whether the devices are in working order, for whichever direction the current is flowing in and however small the current, it will produce a difference in glow, between the red and green lamps, which indicates that the device is operative.

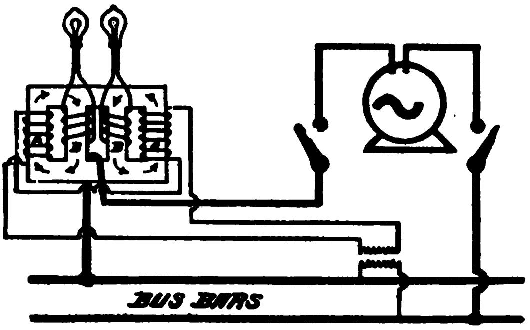


FIG-3

ANDREWS CURRENT DIRECTION INDICATOR

The protection of the transmission lines presents many problems of interest. The simple case where the feeders starting from the bus-bars transmit power to separate receiving points is taken care of by excess-current circuit-breakers; but where the feeders are also connected together at the receiving end, some other system of protection is necessary. An efficient system of protection for multiple transmission lines should, while normally allowing all the lines to be in use at once, be capable of preventing any excessive rush of current in case of a fault on one of the lines and should include devices for entirely cutting out such faulty line without serious disturbance of the rest of the system. Attempts have been made to provide such protection by the use of excess-current breakers at the generating end and reverse-current breakers at the receiving end, but with very little success, the failures being due to one or both of the following defects in the system:

(1) That it does not prevent the sudden rush of current through the healthy mains to the faulty one.

(2) In the case of a low-resistance fault the pressure falls so low at the receiving end that the reverse-current-breakers (if they depend on the action of potential coils) fail to operate.

The system devised by Mr. L. Andrews, which is briefly referred to in another paper, includes a choking-coil which absolutely prevents any excessive rush of current in case of a fault on one of the mains, and this in combination with automatic cut-out devices fulfils the necessary conditions for complete protection without interruption of the supply. As used in England, this system has only been applied to duplicate mains, and for this a single choking-coil is used connected across the two mains, with a tap from the middle of the winding going to the receiving apparatus. By the use of more chokers the system can be adapted for any number of feeders in parallel. By the use of choking-coils connected in this manner, the principal difficulties usually encountered in the protection of multiple transmission lines are avoided; sudden current rushes are absolutely prevented; the voltage at the receiving end is maintained, and consequently the operation of the automatic devices can be relied on.

Fig. 4 represents a duplicate transmission line protected at the generator end by excess-current circuit-breakers and at the receiver end equipped with differential choke-coils. For the sake of simplicity, only one polarity of the system is shown thus equipped. When a short-circuit occurs on, say, B feeder, there is a big rush of current from the generator to the fault through B, and this operates the excess-current circuit-breaker at the generator end. Without the choking-coil, there would also be a rush of current to the fault via the healthy feeder and this would very probably operate the remaining circuit-breaker and interrupt the supply. The choke-coil entirely prevents this, for as soon as the current flow in the two halves becomes unbalanced, an e.m.f. is induced which opposes the unbalancing, and the only current which flows to the fault through the healthy feeder is that required to magnetize the choking-coil. While the short-circuit is maintained and before the faulty feeder is cut out, the receiver voltage will be 50 per cent. of its normal value. The switch B, being thrown, the faulty feeder is cut out, the choking-coil short-circuited and the supply is continued at normal voltage. In the apparatus exhibited, a special form of automatic device is used for operating the feeder switches and this device is illustrated diagrammatically in Fig. 5. The two small transformers are each magnetized by two windings connected across the system so that the induced flux of one of them depends on the voltage of

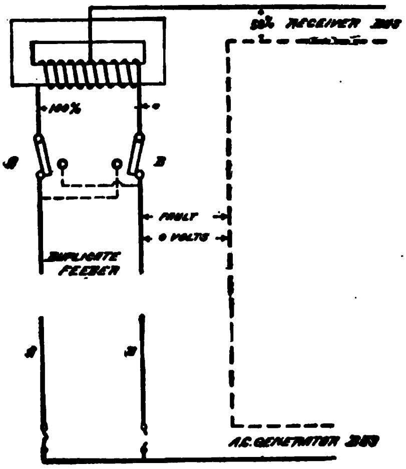


FIG-4.

DUPLICATE FEEDER PROTECTION
(CONDITION WHEN B FEEDER HAS FAULTED)

the particular feeder and the other on the mean voltage of the two feeders. Referring to Fig 5, the coils A and B are excited from the feeders A and B while coils C C are connected as shown from the common terminal of A and C to the opposite polarity of the system. Normally, the two windings on each transformer magnetize in the same direction; but in case of a short-circuit on one of the feeders, while the current in C C will continue in the same direction, the current in the coil connected to the faulty feeder will reverse, and the opposition of the two windings will send a flux through the middle leg on which is wound the secondary coil connected to the release-coil of the feeder switch.

As the essential feature of the Andrews system is the use of the special choke-coils. a few words on the design of these coils is necessary. Under normal conditions there is no flux in the iron core and the only losses are those due to the ohmic resistance of the coils. When a fault occurs, the ampere-turns of the two coils will be unbalanced and the resultant of the two will produce a magnetic flux which reacting on the windings will tend to prevent the unbalancing of the currents. For complete protection, it will be seen that this flux must be sufficient to induce the full line pressure in the coils, but under this condition there is no objection to the iron being highly saturated; and consequently by careful attention to the design a very compact choke-coil can be produced.

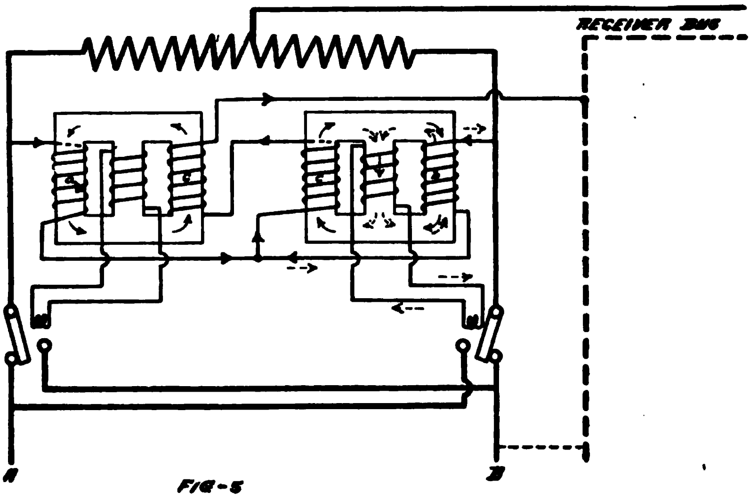


FIG-5

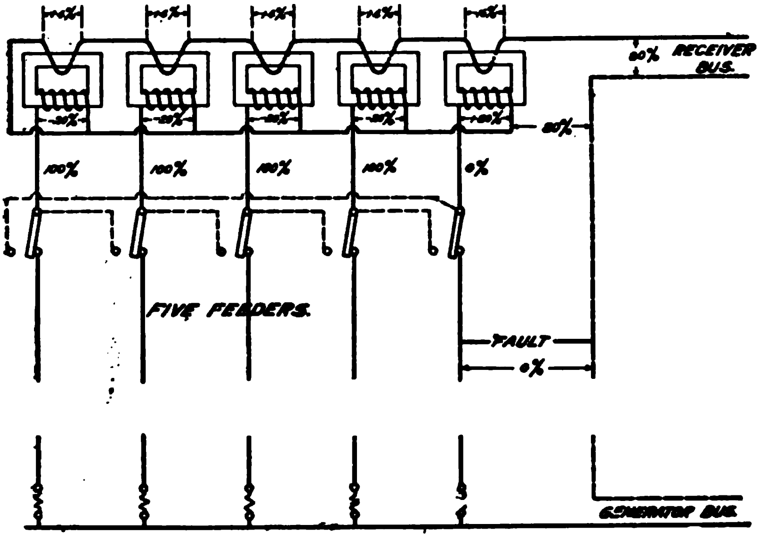
(BROKEN-LINE ARROWS SHOW CONDITION WHEN B FEEDER HAS FAILED)

To sum up, the use of choke-coils in this manner will introduce a small extra copper loss into the system, in return for which it will confer complete freedom from trouble due to short-circuits on the line by its direct action of choking back the short-circuit current.

Discussion of Wilson Paper.

Mr. H G. Stott:—I would like to inquire how that device can be applied to more than two lines.

Mr. Wilson:—The accompanying diagram shows the method of protecting five parallel feeders. For simplicity only one side of the system is shown protected, but if necessary the other side can be similarly protected, in which case the size of each choking coil will be one-half. In the case of a dead short-circuit occurring on one of the five feeders, the rush of current from the four healthy ones will be prevented by the choke-coils and without operating any switches at all the system will continue to operate with the receiver voltage reduced by one-fifth, *i.e.*, reduced to 80 per cent. of its normal value. If the short-circuit persists, the switch on the faulty feeder can be thrown and the system will operate at normal voltage with one feeder taking up double the load of each of the others. The extra drop in this feeder will be automatically compensated for by the choke-coils, so that there will be no appreciable change in the regulation of the system, due to the cutting out of the faulty feeder. If the fault is a high resistance one, the effect on the receiver voltage will be very small. With such a system perfect protection is obtained without operating any switches at the receiver end, and signal-lamps connected across the choke-coils afford the necessary indication for localizing the fault.



AUTOMATIC PROTECTION OF FIVE PARALLEL FEEDERS
(CONDITION OF ONE FEEDER DEAD SHORT CIRCUITED.
FIGURES REFER TO PERCENTAGE OF NORMAL VOLTAGE)

President Scott:—The point Mr. Stott has in mind is, if he has a 3-phase circuit with 10 or 20 feeders, sufficient devices of this kind might fill up his station.

Mr. Wilson:—That is quite so, for a large number of feeders.

[Communicated after Adjournment by Mr. Leonard Wilson]

In discussing the adoption of automatic protective devices, it must be remembered that the true function of such devices is to assist in maintaining continuity of supply, and from this standpoint they readily divide themselves into three classes:

(1) Devices which by prompt action prevent a faulty part of the system from interrupting the supply, but cannot under any circumstances themselves interrupt the continuity of supply.

(2) Devices which while protecting the rest of the system from being interrupted by a local fault, in so doing themselves interrupt the continuity of supply at that point.

(3) Devices for the protection of apparatus but not directly instrumental in maintaining continuity of supply.

In many cases, devices of the two latter classes should be hand-operated, whereas those of class (1) should in all cases be automatic, as the objections usually made against automatic devices do not hold when the conditions are such as are here implied. The ideal condition, therefore, for an automatic device, is where in case of trouble the immediate operation of the device is necessary to prevent interruption of the supply, and further, in case of less serious trouble, the operation of the device cannot affect the continuity of supply. These conditions are fulfilled by the reverse-current circuit-breaker (when placed in its proper sphere), and particularly by the feeder protective system previously described.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, New York, July 1, 1903.

METHODS OF BRINGING HIGH-TENSION CONDUCTORS INTO BUILDINGS.

BY C. E. SKINNER.

One of the points in the design of high-tension transmission lines which seems not to have received general attention is the method of supporting and insulating the conductors which connect the transmission circuit with the apparatus in the generating stations and substations. Each engineer follows the plan which seems to him best for his particular set of conditions. In some cases the line is brought through a hole in the wall; in others through an elaborate system of tubes placed in the wall; in others, through a piece of insulating material of some kind set in the wall; in others, the line is entered through an elaborate tower built for the purpose on the top of the building; in still others, it is taken directly through the roof of the building.

It is manifestly impossible to prescribe any fixed method for all voltages and all locations, as the requirements of each plant are varied by the local conditions, but much would be gained if the general requirements were outlined in such a way that designers of buildings and designers of plants could follow some general and accepted scheme which is known to be satisfactory for any given set of conditions. It is the purpose of this paper to discuss the general requirements rather than to give specific designs, although specific methods must necessarily be referred to in this discussion.

The method to be followed will depend on the following conditions:

(1) The voltage of the transmission circuit.

(2) The climate in which the plant is operated.

(3) The size of the high-tension conductor.

(4) The kind and height of building used.

(5) The conditions of approach to the building and the location of the apparatus in the building to which the high-tension line is connected.

The requirements which must be met are:

(*a*) *The Maintenance of Proper Insulation of the Circuit.*—To maintain proper insulation, it is necessary either to allow sufficient open space about the wire to prevent any possibility of the current striking across to the walls or surrounding material; or some insulating medium, such as a tube, must be applied to the wire to give the proper insulation.

(*b*) *The Prevention of the Entrance of Rain, Snow, Cold Air and Dust.*—The entrance of moisture, snow, and dust, should be prevented both on account of damage to the contents of the building, and on account of the weakening of the insulation at the point of entrance. In most climates it is necessary that all openings be closed for at least a portion of the year.

(*c*) *The Proper Mechanical Fastening of the Line Wire.*—The end-strain of the line must be taken up, and it is often convenient to combine the plans for taking up this strain with those for entering the building. This is particularly true where the transmission conductors are very large. It is also necessary to hold the wire in a fixed position where it passes through the opening into the building. This requires a more rigid line construction than is necessary away from the building.

(*d*) *Reliability and Simplicity of Construction.*—It is self-evident that the construction must be such that it will be reliable under all circumstances. There are usually a sufficient number of troubles on high-tension transmission lines due to circumstances beyond the control of the engineer, without introducing any extra risk at the point where the wire enters the building. Usually, as in most other work, the simplest form of construction will be found the most reliable.

In general, wires are best brought through the walls of the building. The simplest form of construction consists merely of an opening in the wall sufficiently large to allow the proper air insulation between the wire and the wall, this opening being suitably protected from rain either by means of a large pipe set in the wall, sloping outward, or by a sufficint extension of the roof above, or both. The requirements of this form of construction are that the wire be a sufficient distance from the pipe, so that there will be no possibility of striking across under any conditions. The pipe should always be considered as "ground," regardless of the construction of the building. The cross-arms holding the wire inside and outside of the building should be sufficiently near and so braced that the wire will remain central in the pipe. This construction can be used to advantage only in dry, warm climates.

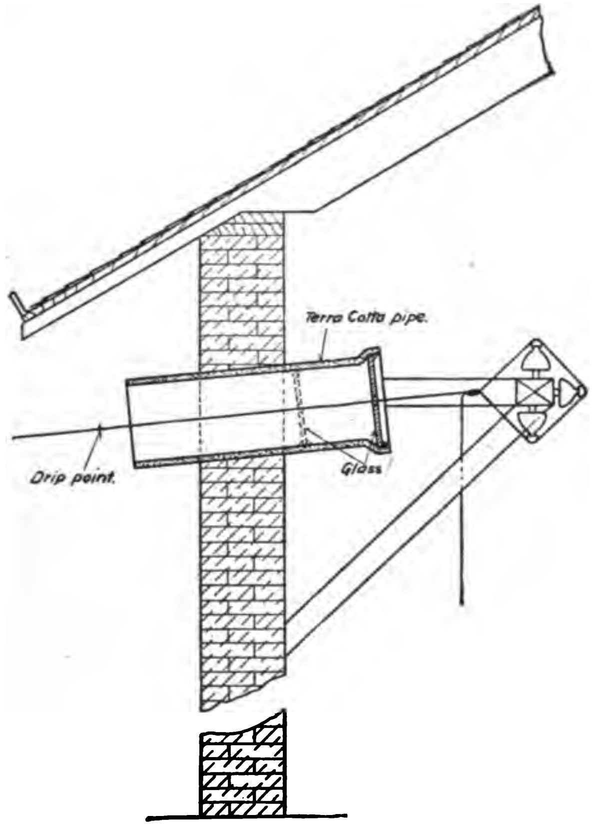


FIG. 1.

In most climates provision must be made for keeping out rain, snow, etc. With potentials of 15,000 volts or lower a disc of glass or other fireproof insulating material placed over the wire at the inner end of the pipe will usually accomplish this purpose. In this case the tube must be sufficiently large so that the surface insulation over the insulating disc used will be ample to prevent trouble under the worst conditions which may occur. When there is any danger of condensation of moisture due to differences of temperature inside and outside of the building, two discs a little distance apart should be used. These discs may be cut so as to be placed in the pipe itself, or they may be cushioned and simply swung on the wire, lying against the ends of the pipe. The surface insulation of the discs used should never be less than that of the line insulators, and as they will usually be less advantageously placed than the insulators, extra distance should be allowed, if possible.

With potentials above 15,000 volts, this form of construction becomes unsuitable on account of the large size of opening required to give the necessary insulation distance over the discs. This may be true even with potentials below 15,000 volts under very adverse conditions. For the higher voltages, a long insulating tube of small diameter and very heavy wall may be placed over the wire and passed through a slab of insulation set in the wall of the building, the whole being protected from driving rain by an extension of the roof. The insulating tube should slope outward in all cases. Some form of drip point should be provided on the wire just outside the end of the tube. The insulation slab holding the tube should be large enough to prevent actual breakdown even though the tube is broken. Both tube and slab should be of fireproof material. This form of construction has been successfully used for potentials as high as 50,000 to 60,000 volts. The chief difficulty is in securing the proper insulating tubes. Glass and porcelain are electrically the best materials for the purpose, but when these are used it is usually necessary, on account of their lack of mechanical strength, to take up the end strain outside of the building by a suitably guyed pole.

The tower-construction may be necessary where the building is low, and the line wires must be carried at a considerable elevation in the immediate neighborhood of the building. It is generally very cumbersome and unsightly, and the bringing of the wires through the side of the tower presents the same problem as bringing them through the side of the building.

The bringing of the wires directly through the roof of the building, while possible, requires that extra precautions be taken to secure sufficient insulation and to keep out all moisture. This method, however well carried out, will probably constitute a danger point in the system.

In general no combustible material should be used near the line wire, even when separated from it by insulating material sufficient to withstand the strain. Leakage or brush discharge is liable to cause burning sooner or later, and such burning is more serious at the building than the burning of a pin or cross-arm on the line.

The accompanying illustrations, Figs. 1 and 2, are intended to show diagrammatically the two general plans recommended in this paper. Both plans, practically as shown, are in successful use by important transmission plants. It is expected that each engineer will find it necessary to make changes in details to suit his particular case, but it is believed that the plans proposed may be made effective for any transmission circuit.

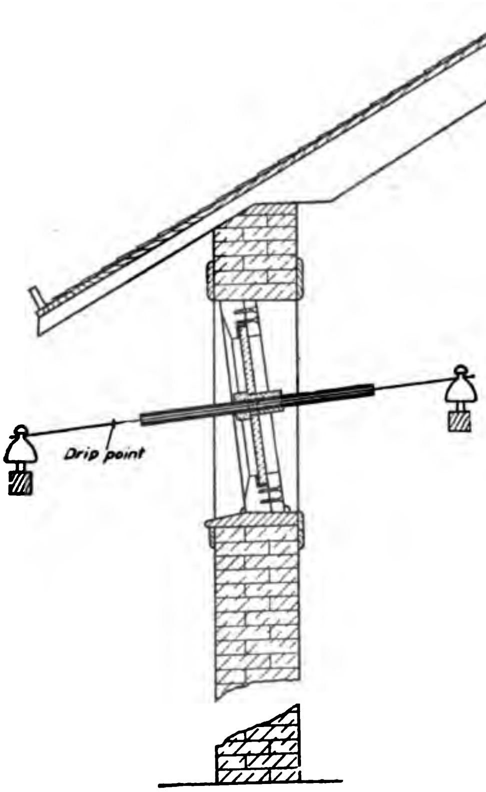


FIG. 2.

The method of bringing high-tension wires into buildings should be carefully considered at the time the building is designed and proper provision made. It often happens that this point is given no consideration whatever, and the result is an unsightly and unsuitable arrangement made after the completion of the building and at an increased expense.

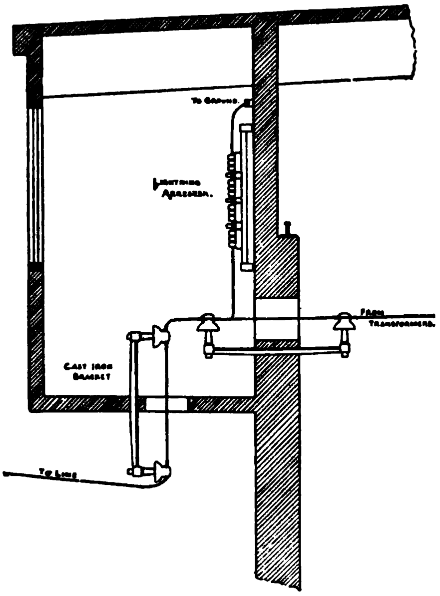
It is hoped that those having practical experience with the design and construction of this particular feature of the transmission line will take an active part in the discussion of this paper, and that by this means the INSTITUTE may be able to furnish general recommendations covering this subject.

DISCUSSION OF MR. SKINNER'S PAPER.

MR. SKINNER:—I have here several communications which I will read.

MR. HENRY FLOY:—Because of its simplicity and reliability, the writer believes there is nothing quite equal to a plain but generous hole in the wall through which the wire rigidly supported, may pass. This form of construction modified as hereafter shown, is applicable to any voltage, and almost any climate.

I consider that the use of glass plates, as suggested by Mr. Skinner in Fig. I., or conductors insulated for a portion of their length as in Plan II., are more or less objectionable because of the constant menace of leakage and grounding of the system, through the wall of the building. The accumulation of dust or moisture on the glass plates, or the deterioration of rubber or paper insulation due to exposure and weather will sooner or later end in a shut-down; glass tubes and plates are always breaking and never make a really good mechanical job.



If the station is provided with an overhead traveling crane, it will usually be found more convenient to bring the wires into the building through one of the walls rather than into a tower.

Having tried several different methods, none of which were wholly satisfactory, the writer devised the scheme shown in the accompanying sketch, which explains itself. This form of construction has been successfully used in a concrete-steel building, where the roof beams of concrete were carried beyond the walls of the building and made to support a gallery, which serves as a lightning-arrester house; thus, the satisfactory introduction of the wires into the building and a proper fireproof room entirely separated from the station for the location of the lightning arresters, is provided. The iron brackets on which the wires are first supported, may be set either in the floor of the gallery or in the wall of the station. In either case all water drips from the wires before the latter turn vertically to pass through the floor of the gallery. At the same time any small amount of rain, snow or dust which may blow up into the gallery will not continue on through the second hole into the station. Moreover, the two apertures, one leading into the gallery and the other from there into the station, being at right angles to each other, prevent any large amount of cold air entering the station. One building provided with this form of admittance was not particularly uncomfortable though the outside temperature was as low as 27° Fahrenheit below zero. The maintenance of proper insulation is always insured; proper mechanical fastening of the line wires secured, and the reliability and simplicity is all that could be desired.

MR. SKINNER:—It should be noted that Mr. Floy's plan does not contemplate in any way taking up the end strains of the line wires. This must be done away from this point.

The other communication I have is from Mr. O. H. Ensign, Chief Electrical and Mechanical Engineer of the Edison Company of Los Angeles, California.

MR. O. H. ENSIGN:—We use, for 30,000 volts, plain 12-inch sewer-pipe wide open. Our temperature never goes to zero. It is cold only for short periods. I do not beleeve that unless considerable protection is given in the way of extension of the building, any sort of glass plate or marble supporting special insulators would be satisfactory, exposed to the weather.

MR. SKINNER:—Here is another discussion by A. L. Mudge.

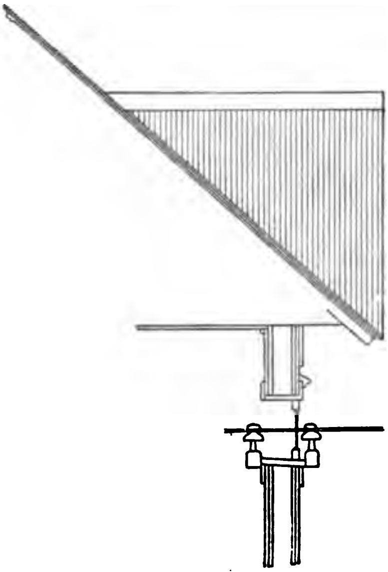
MR. MUDGE:—Would suggest that the terra cotta should be closed at outer end to prevent birds and insects getting into, or building nests in, the pipe. I find that a good ice and snow break on a sloping roof is V-shaped, and is much stronger than a single horizontal strip and also tends to let the roof free itself of snow. These strips can either be made of wood or of two lengths of angle iron bolted to the roof.

PRESIDENT SCOTT:—Another from Mr. F. C. Pierce.

MR. PIERCE:—Referring to the article: Page 314, Art. (5), (C), I do not believe in allowing the wall of the building to take the strain of the line. the last poles of the line should be braced or guyed; the number of poles guyed being determined by the number and weight of the line wires. In all cases I have seen, the wall, even if very heavy, will eventually come loose or bulge.

Where the strain is taken on the line: a X-arm just outside and one just inside the wall, fastened rigidly to the wall, will hold the wires in the centre of the slab of insulating material and exert no strain thereon.

I enclose rough sketch of our method of entering wires in the power house.



We found it necessary in cases where we enter under the eaves as in the sketch on p. 317, Fig. 2, to put a false dormer above the entrance, as otherwise the ice and snow slides down, catches on the wires and accumulates between the wires and eaves until the wires are either broken or pulled out of place.

The substation wires enter the gable ends. The slab of insulating material is 12″ x 12″ plate glass with 2″ hole through center. Since putting the dormer on power house we have had no trouble whatever from our entrance wires.

[Discussion Contributed by J. Harisberger.]

My experience has been with the construction as shown in sketches 1 and 2, pages 315 and 317. The Snoqualmie Power Company adopted at the very beginning the arrangement shown in Fig. 2, and with all of its high-tension troubles, it has yet to experience its first trouble with this style of construction for entering buildings. In some of the buildings the wires enter with the construction shown in Fig. 1 and in every instance when the high-tension lines became grounded for one reason or another, there was a discharge across the glass plate to the terra cotta pipe and which is evidence, in my opinion, that with a voltage as high as 30,000 it is not the best, unless a terra cotta pipe of an unpractical diameter is used.

[Communicated by M. H. Gerry, Jr.]

Mr. Skinner has stated the essential requirements for entering high-tension wires. There are a number of excellent methods in common use, all of which give good results when properly applied. Fig. No. 1 is an excellent construction in use in several plants operating at 40,000 volts. This arrangement consists of a double, or triple, window sash set in an ordinary frame, the glass having openings in the centre in which are placed insulating bushings, or tubes. A water shed to keep the rain from the glass is sometimes added.

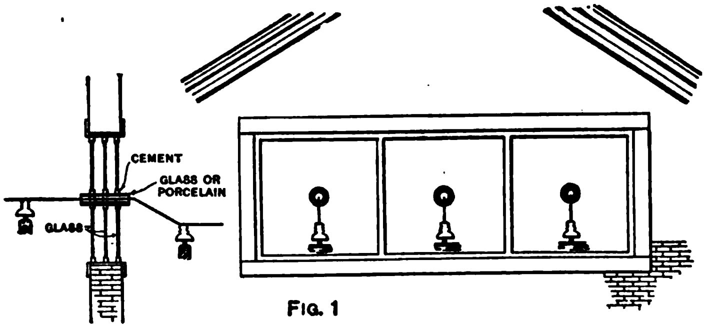


FIG. 1

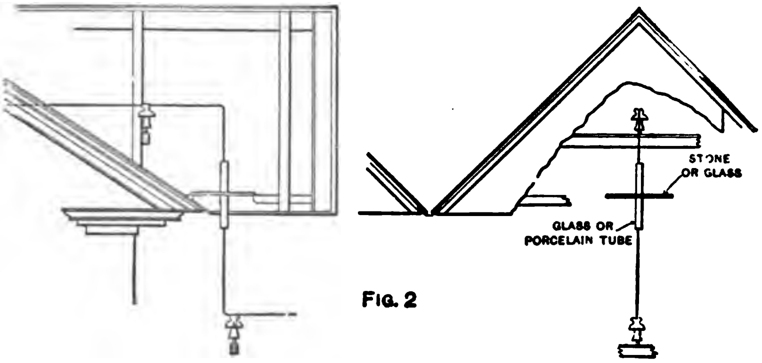


FIG. 2

Fig. No. 2 is a method frequently advocated, and in use for moderate pressures to a certain extent. It can be made to give good results, but involves special building construction.

Fig. No. 3 is a common method of entering high-tension wires through tile pipes. This method is an excellent one, and will give good results even up to pressures of 30,000 volts. Entrances of this design should always be made, if possible, through gable end of the building and not under the eaves, as shown by Mr. Skinner. If impossible to enter at the end of the building, then a rain-shed should be provided over the wires, this being especially essential in cold climates, where ice forms readily.

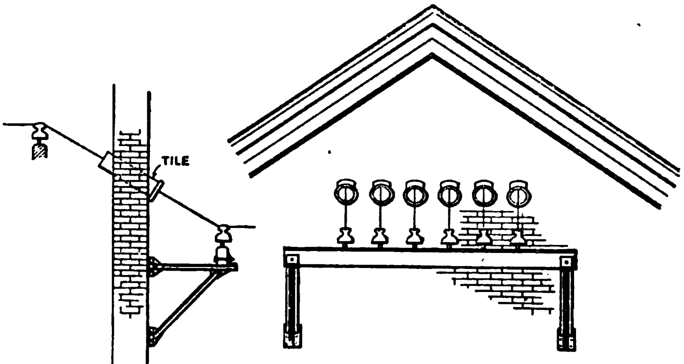


Fig. 3

Fig. No. 4 is a simple method of entering high-tension wires as applied to an iron building. The glass tubes shown are four feet in length two inches in diameter, and from five-eighths to three-fourths of an inch in thickness. This method is now in regular use at 50,000 volts.

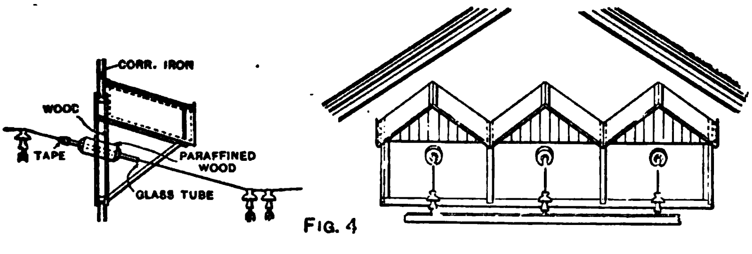
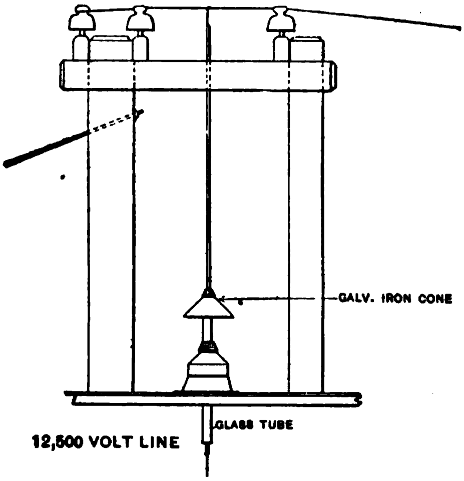


Fig. 4

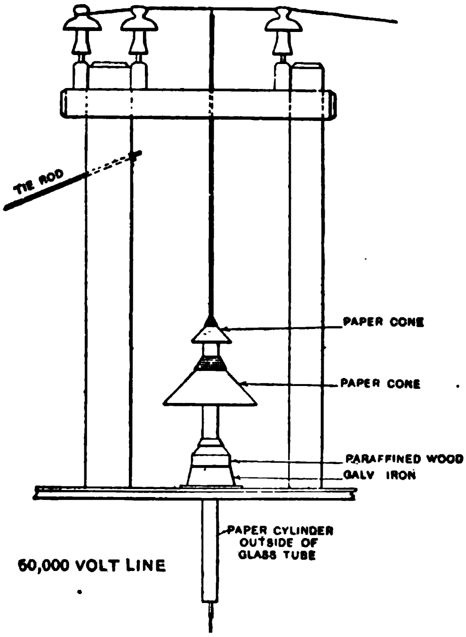
Figs. No. 5 and No. 6 are methods of entering wires vertically through the roof. Fig. 7 is a detail of the roof insulator, used in connection with the arrangement as shown in Fig. No. 6. The drawings show the construction clearly and require no explana-

Fig. 5



END ELEVATION

Fig. 6



END ELEVATION

tion. These vertical entrances are in use at the Canyon Ferry Plant of the Missouri River Power Company, and give good satisfaction. The above methods are selected as representing current practices. There can be no one method of entering high-tension wires. It is always a question of engineering detail, which should receive special treatment in each particular case.

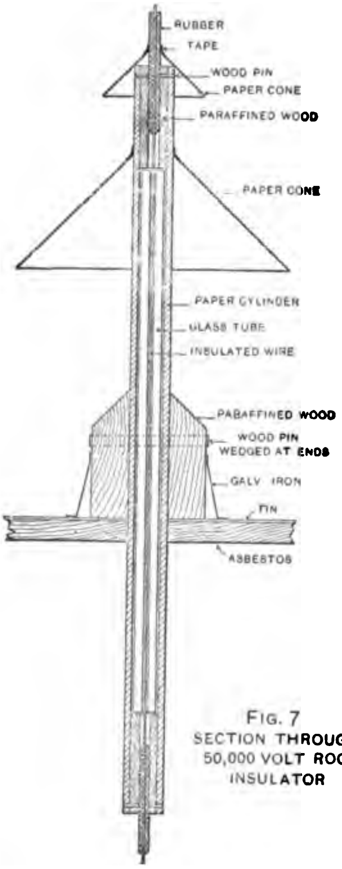


FIG. 7
SECTION THROUGH
50,000 VOLT ROOF
INSULATOR

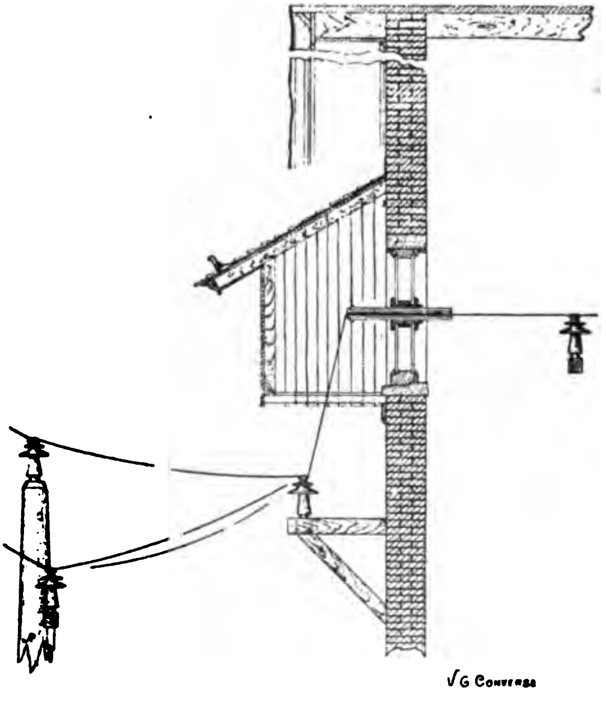
PRESIDENT SCOTT:—Mr. Skinner's paper, on the "Methods of Bringing High-Tension Conductors into Buildings," is open for discussion.

MR. MERSHON:—I have used a number of different methods of bringing wires into buildings, some of which have already been described. The method of a tile and a flat glass plate, has been used, I think, quite a long while; also that of a glass tube in a wooden bushing going through the wall, for voltages of 25,000 or 30,000. The latter is a good method of bringing wires into buildings except for the difficulty of getting glass tubes. Some times I have had no difficulty in getting satisfactory glass tubes; at other times tubes obtained from the same manufacturer will all go to pieces if, being warm, they are subjected to a blast or draft of cold air, such as would result from opening the door of the station. So I have come to feel a little bit afraid of the use of glass tubes.

Now, as to the size of the glass plate and the distance which the voltage will go over it. Some time ago I had occasion to install a tile and a glass plate arrangement because there was not time to get anything else, and the largest tile obtainable was 24 inches. That size was put in on a 50,000 volt line, which has been in operation in all kinds of weather for four or five months without any trouble. At times the frost gets so thick on the glass that you cannot see through it and, if the line has been shut down for a little while and a great deal of frost has collected, there is a discharge over the glass until the frost is melted; but after it is melted near the wire the discharge stops almost altogether. Although we have had no trouble at all in this case, I think a greater distance than 12 inches over the surface of the glass plate from the wire to the tile in a brick wall is advisable for this voltage. I think this question of entering buildings is a good deal like the question of insulators, in that it depends somewhat on the climate. There are places where the climate is such that the method I have just described for a 50,000 volt circuit would undoubtedly give trouble.

Mr. R. F. Hayward:—There is no doubt that the question of climate cuts a very big figure in the selection of the methods for entering buildings with high-tension wires. I think this method of using a tile is open to objection, and a good deal of trouble comes from it. I do not think that any outlet which has for its protection a covering for building outside the power house where the wire comes in, then up and then through, is very nice, for the reason that birds do get in. The most successful outlet that I know of is one that was put in at the Murphy mill and has been running on 40,000 volts for, I think, four years. There is a brick wall in the gable end. The outlets are, I think, four feet apart. The holes in the brick are, I think, 18 inches. They may not be more than 14 inches. In those are set two plates of glass, each plate of glass flush with the outside, then another flush with the inside, of the brick; a hole about 2½ inches in diameter drilled through this and another glass tube placed in it. There was great difficulty, as Mr. Mershon has mentioned, in getting good glass, but they have got it, and that glass has never broken. There has never been a short-circuit or a breakdown, and that gable end faces the southwest storms, where all the sleet and rain comes from. We are using that kind of outlet for all our work in Utah, only instead of using the glass tube we are going to use porcelain tubes, because I think we can get them stronger, and we shall simply increase the size of the plate glass to about two and even three feet square. I think that people do not appreciate how effective in practice a simple piece of plate glass is. On 16,000 volts I have a piece of 12-inch plate glass with a ¾ hole drilled in it and wires passing right through, and have never had the slightest trouble, although we frequently have severe storms in winter. I think that the most important thing in outlets is lots of space and not cumbering the outside of your building with any extra structure. Leave it clear, so that nothing can get up against it, and where everybody can see it.

Mr. V. G. Converse:—I am hardly prepared for an impromptu discussion, but I have a few ideas on this subject, one of which I think is of the utmost importance with very high voltages. It is that the insulation into a building should of itself be protected. It should be protected so that anything coming in a horizontal line, such as rain, snow or dirt that is blown will not decrease the resistance of the insulation. Two figures show the extension of the roof brought down to such a point that to my mind it leaves off just where it begins to be of value.



The tile shown in Fig. 1, seems to me to possess a very bad feature in being left open on the exposed side. This construction may suffice, and I know of several cases where it is in use, but it certainly is open to the objection of being free to receive anything that may lodge in it. I think that Fig. 2 is a much better construction, but it could be improved upon by using several tubes, rested one within the other. Mr. Mershon has stated the objection to glass tubes, and I would recommend the substitution of porcelain. I do not think that porcelain is always a good article to use, but it is in this case. Suitable glass tubes are not made in this country and are very difficult to get anywhere, while porcelain tubes are a standard article of manufacture and they can be gotten in lengths up to three feet, I believe, and in a variety of diameters, which will nest very satisfactorily. I would make the further suggestion with reference to Fig. 2, that instead of one glass plate, there be two glass plates, spaced some five or six inches apart. This will give additional support, and afford an inside space which should tend to prevent the accumulation of frost. As to the point of the extension of the gable, as first mentioned, I think that there is the insulation of the whole structure. To my mind, the most uncertain point of the insulation in Mr. Skinner's second figure is the surface distance from the outer end of the tube over the glass plate. This cannot be very many inches and should be protected. I would advise that the gable be extended down to a point considerably below the wall insulation. The line wires should be carried from the anchor pole to a point several feet below this gable, and up to the tube insulators and into the building. The lines may be held in this position by a bracket supported on the wall, below the gable. If the lines are heavy they may be further supported by line insulators within the gable, so that there will be no strain on the tubes or glass plates. I furnish a sketch embodying my ideas.

MR. P. H. THOMAS:—To my mind Mr. Converse's suggestion of a rain-shed is an excellent one. By extending the roof a considerable distance from the wall and running it low down, building a baffle-plate from the ground up, leaving just sufficient opening to carry the wires in, and carrying the wires down and up as he suggests, you get the conditions of an indoor inlet at the main wall, where the plate glass and tubes are used. With the possible exception of the temperature outside, the conditions or interior construction will be admitted to be very much superior to those out of doors. Now, by changing the usual out-door inlet to an indoor inlet nine-tenths of the trouble would be avoided, and this can be easily done by the rain-shed spoken of. Sometimes it might be more convenient to obtain the protection by bringing the the rain-shed inside the building; that is, have a large opening in the wall and building a small room or large box up near the top, for bringing in the wires and then putting the true inlet on the farther wall, where it would be thoroughly protected from the weather.

There is one other point; ordinarily, I think a great deal will be gained in the long run by mounting the true high insulating inlet in an insulating panel, made as nearly fireproof as possible—something of the nature of marble would of course be the best—but with a large number of substations this would be too expensive. For a great many climates, it would be wise to use a wooden panel in which to mount the glass or porcelain inlet. This panel in such a case should if possible be made of a number of different pieces of wood with the grain running in different directions, and should of course be as well treated and prepared as possible. There is a certain danger of fire, but this is a minimum, I think, with good construction, and with the rain-shed of which we have spoken.

MR. P. M. LINCOLN:—There is just one point in the scheme mentioned by Mr. Converse that I would like to bring up, and that is the matter of taking up end strain. If you adopt that scheme, you have got to take up your end strain on the line outside of the building. That means taking it up on the standard insulators with the usual pins. Unless there is a special construction it is difficult to take up the strain on a heavy line in that manner. The end strain should be taken up by a strain insulator inside, as represented in Mr. Skinner's sketch No. 1. The great advantage of that to my mind is that the end strain of the line is taken by the insulators mounted inside the building, and you can put your insulator in any position, without having petticoats in such a position as to fill up with water and become useless.

[COMMUNICATED AFTER ADJOURNMENT BY DR. LOUIS BELL.]

For all high voltages, I prefer the arrangement shown in Fig. 2 in Mr. Skinner's paper. It is thoroughly effective and has the great merit of demanding ample space between wires. A mania for compactness has been responsible for more trouble in high voltage systems than any other one cause with which I am acquainted.

Wire towers for high potential lines should be avoided, first, last and always, together with tunnels, conduits and every other device for getting high-tension wires compactly stowed away out of sight. My own personal rule is to use wide spacing and to carry all wires in obtrusively plain sight until they get out of the building and go upon the line proper.

The high voltage wires themselves and all their connections should be so placed that their whole arrangement is evident from a cursory glance, and the higher the voltage the more need for caution in this respect.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 1, 1903.

THE GROUNDED WIRE AS A PROTECTION AGAINST LIGHTNING.

BY RALPH D. MERSHON.

Some of the transmission lines of this country have installed upon them as a protection against lightning one or more wires strung parallel to the power wires and grounded at intervals. There is a difference of opinion amongst those operating such lines in different parts of the country as to the efficacy of this device. The importance of the subject makes it desirable to have an expression of opinion upon it from those members of the INSTITUTE who have had experience in operating such lines or who have given the matter close consideration. This can perhaps be best arrived at by a discussion on the subject.

THEORY.

There are three ways in which lightning can affect a transmission line; by a direct stroke, by electromagnetic induction and by electrostatic induction. Protection against the first of these would be almost impossible, certainly impracticable. Fortunately, lines are not often struck by lightning. The second, electromagnetic induction, is, in the opinion of the writer, a theoretical possibility—nothing more. It is against the effects of the third, electrostatic induction, that lines are to be protected, whether by lightning arresters or by grounded wires.

The theory of the electrostatic induction action may be explained with practical accuracy as follows: The whole transmission system, line, transformers, etc., may be regarded as an electrostatic conductor, insulated from the earth. Suppose a cloud heavily charged with, say, a positive charge, to move up to the region over the transmission line. There will be a positive charge " set free " on the transmission system and it will have a tendency to pass to earth. It will pass to earth by gradual leakage over and through the insulation of the system if the approach of the cloud is slow enough to give time for such leakage; if not it may puncture the insulation and thus pass to earth. The intensity of the charge will depend upon the potential at the line wires due to the charge of the cloud. Suppose there be near the transmission wires other wires parallel to them and grounded at frequent intervals. They will also be subject to the inductive action and the charge set free upon them will pass to earth as fast as liberated, the " bound " charge of the opposite sign of that of the cloud remaining and depending for its magnitude on the potential due to the cloud and the electrostatic capacity of the grounded wires. Under these conditions the intensity of the charge on the transmission wires will no longer depend only upon the potential at them due to the cloud, but upon the combined action of the charge of the cloud and the bound charge of the grounded wires. In other words, the potential of the line wires will be equal to the difference of the potentials due respectively to the cloud and the grounded wires and will in general be less than that due to the cloud. This action constitutes what may be designated as the " shielding action " of the grounded wires.

Return now to the condition where with no grounded wires the system has been gradually charged and the charge has gradually leaked away, leaving a bound charge of negative sign on the system. Suppose now the cloud be discharged by a lightning flash to earth. The potential due to it at the transmission wires is now zero and there is consequently left upon the transmission system the negative charge which was previously " bound " but is now " free " and which has a tendency to pass to earth and will probably do so suddenly, since the charge has been rendered free suddenly. Its passage to the earth may mean a puncture of the insulation of the system. If, however, we assume that the grounded wires are again present and the charge bound on them by the cloud and set free upon them by the lightning flash can readily pass to earth, there will be less tendency towards the puncture of the insulation of the system because of the fact that, as previously explained, the impressed potential of the line wires before the flash is less with the grounded wires than without them. If the charge on the grounded wires cannot pass readily to earth the charge on them will tend to set free a negative charge on the line wires, which will be added to that set free on the line wires by the lightning flash. The worst condition would be that under which the charge on the grounded wires could not pass to the ground at all, in which case the sum of the two charges on the line wires will be just equal to that which would have existed if there were no ground wires. The passage of the charge from the grounded wire to ground will always be more or less obstructed by the inductance of the discharge path, the effectiveness of this inductive obstruction depending upon the suddenness with which the cloud discharges. This inductive action of the ground wires due to the charge left upon them we will designate as the " direct action " of the wires.

The " shielding action " of the ground wires may be calculated by making assumptions which will approximate to a degree those which obtain in practice, but the calculation of the " direct action " is less satisfactory since it involves a number of assumptions, all more or less speculative in their nature. This is due amongst other things to the fact that we cannot know how long the lightning flash will last or whether it will be oscillatory or not. Furthermore, we do not know what the dielectric strength of the insulation of the system will be for periods of time so short as those involved under the conditions mentioned. We do know, however, that under the worst conditions that can obtain the insulation stress due to the " direct action " of the grounded wires can be no greater than though they were not present and will in general be less. We also know that whatever be the maximum value of this insulation stress it will diminish rapidly either in an oscillatory or non-oscillatory manner, the rapidity of the diminution depending upon the freedom of the discharge path from obstruction. It is to be noted that the time-element of dielectric strength is not involved in the calculation of the " shielding action " to the degree that it is in the "direct action"; since in the former case the charge comes on to the system more or less gradually and we may assume without great error that ordinary values of dielectric strength hold.

In order to get an idea as to the magnitude of the " shielding action " let us calculate its effect under the most simple conditions. Suppose we have two No. 00 wires stretched side by side on a pole line 20,000 feet in length, the wires being one foot apart. Call these wires A and B. Suppose first that both wires are insulated from ground and that the space occupied by them is raised by the inductive action of a cloud to a potential V above the earth. The expression for the potential of a long cylinder or wire of length l and diameter d, having upon it a charge whose density is δ is

$$v_1 = 2\,\pi\, d\, \delta \log_e \frac{2l}{d}$$

The potential outside such a wire at a distance s from its axis is

$$v_2 = 2\,\pi\, d\, \delta \log_e \frac{l}{s}$$

Each of the wires A and B has upon it, therefore, a free charge of such a density that

$$V = 2\,\pi\, d\, \delta \log_e \frac{2l}{d} \quad \therefore \quad \delta = \frac{V}{2\,\pi\, d \log_e 2\,l/d}$$

Now let one of the wires A be connected to earth. The free charge on A goes to earth leaving a "bound" charge whose density is equal and opposite to that of the free charge or

$$-\delta = \frac{-V}{2\,\pi\, d \log_e 2\,l/d}$$

The potential of any point distance s from the wire A and due to the bound charge of density $-\delta$ is, therefore,

$$V_1 = -2\,\pi\, d\, \delta \log_e \frac{l}{s} = -\frac{V \log_e l/s}{\log_e 2\,l/d}\, s$$

The resultant potential therefore at any point distant s from the axis of the wire A due to the combined actions of the charge on the cloud and the bound charge on A is

$$V + V_1 = V\left[1 - \frac{\log l/s}{\log 2\,l/d}\right] = V\left[1 - \frac{\log l - \log s}{\log 2\,l - \log d}\right]$$

This expression will give the resultant potential at the wire B when A is grounded, if we substitute in it the value $l = 20{,}000$, $d = .3648$ inches $= .0304$ feet $=$ diameter of No. 00 wire and $s = 1$ foot. Substituting these values we have

$$V + V_1 = .297\,V$$

It appears therefore from this rough calculation that if each wire of a transmission line 20,000 feet in length, the conductors of which consist of No. 00 wire, have stretched parallel to it and at a distance of 12 inches, a grounded wire equal in size to the line wire, the potential of the line wire due to a charged cloud could not rise to exceed 30 per cent. of the value to which it would rise if the grounded wire were not present. As a matter of fact, if each of the line wires had its corresponding ground wire the potential to which they could rise would be even less than this because each line wire would be influenced not only by its own grounded wire but by all of the other grounded wires also. However, it is not usually the practice to employ a grounded wire so large as that assumed, and 12 inches is a smaller distance from grounded wire to line wire than would usually have place. The usual variation from these quantities will about compensate for the effect due to a greater number of grounded wires as usually arranged, so that the example taken serves its purpose as furnishing a criterion as to the magnitude of the effect of the grounded wires. It does not and is not intended to furnish a criterion as to construction or practical details.

MATERIAL AND DIMENSIONS OF GROUND WIRES.

Ground wires are usually of galvanized iron. This material is probably as good from an electrical standpoint as any other, since with the rapid flow which must take place at discharge the material of the wire itself will probably make little difference in the obstruction offered to the flow. The size of the wire will have an important bearing since in general the larger the wire the less obstruction it will offer and also the greater its " shielding action." Greater effectiveness will be obtained of course for a given amount of material from a number of grounded wires of smaller size than from a smaller number of larger size. Barbed wire is often used for grounded wires but in the opinion of the writer it has no advantage over smooth wire. It seems to have been adopted with the idea that the points would in some way discharge the atmosphere, but if the accumulation of a charge on the line wires is in accordance with the explanation already given the points cannot be effective in any way.

METHOD OF INSTALLATION.

Usually three grounded wires are installed, one on top of the pole and one on each end of a cross-arm. They are generally tied to glass insulators presumably for mechanical reasons, as all three wires are of course grounded. The wires should be grounded as often as possible, so that the obstruction to the flow between grounded wire and earth shall be kept as low as possible, thus keeping down the direct action of the grounded wire to as low a figure as possible.

RESULTS IN PRACTICE.

The writer has known of a number of plants where grounded wires were installed. In one of these, as the result of a number of years of operation, those in charge of the plant feel sure that the grounded wires furnish a reliable and effective protection against lightning. In some of the other plants those operating think that the grounded wires furnish more or less protection but are doubtful as to the amount. In still other plants those in charge feel sure that the grounded wires are of no value whatsoever and constitute a nuisance and menace because of their liability to break and fall across the power wires. In some of the cases of doubtful success or failure the trouble may have been due to poor grounds or to the wires not having been grounded frequently enough, as in some of these cases the wires were not grounded at every pole. In all of the doubtful cases lightning arresters which were installed in addition to the grounded wires received more or less discharges during thunder storms.

DISCUSSION OF "THE GROUNDED WIRE AS A PROTECTION AGAINST LIGHTNING."

PRESIDENT SCOTT:—This is certainly a very important and very interesting topic, one on which it is very difficult to secure complete and definite information. The conditions surrounding the problem are indefinite and hard to determine, as in fact are all experiments in connection with lightning work. We should be very pleased to hear from those who have had experience with this subject. I think Dr. Perrine has had something to say on this in the past.

DR. F. A. C. PERRINE:—From my own experience, I would say, that there seems to be no question but that a grounded wire on a pole line properly grounded does benefit in lightning protection. In relation to the question as to whether barbs are used or not, I agree with Mr. Mershon that they can have comparatively little effect in discharging the atmosphere, for the reason that the atmosphere that we wish to discharge is a moving atmosphere and not a stationary one. If the atmosphere were a stationary one the barbs on the wire would undoubtedly aid in the discharge. On the other hand, after a cloud has discharged in the neighborhood of the line, and the line and its accompanying guard wire has reached a stationary condition, just before the bomb charge is about to disappear from the line through the ground circuit, I believe that the points on the grounded line will tend to aid the release of the bomb charge from the power line; and while there is not much in favor of the barbs, it would be my opinion that if it is possible to obtain a wire with a point on that is not thereby mechanically weakened, it would be advantageous to obtain such points. But such a wire is not on the market. I agree that it is not wise to fool with barbed wire, because you can get much greater permanence with simple twisted strand wire or single wire.

There is one point that has not been brought out, and that is the question of possible loss of energy due to inductance to the grounded wire. On one line that I am familiar with they claimed that there was a very serious loss of energy due to electromagnetic induction to the grounded wire, the grounded wire making short circuits parallel to the line. I made some tests on this and could not find anything that seemed to be really appreciable. I would also like to call attention in reference to the communication that Mr. Mershon read, to the fact that the power line at Lachine, where they have found no trouble, although only protected by lightning arresters, is a line of long iron poles, where the earth-tension is undoubtedly brought nearer the line than would be the case with wooden poles. We have no practical experience except with one or two lines such as the Lachine line.

MR. MAILLOUX:—In one line in Arizona 25 miles long, which connects at a station at one end, a receiving station at the other end, and a second power station about eight miles from the receiving end, no provision was made for lightning protection except by spark-gap lightning arresters at the stations. In other words, the line, a 3-conductor line, about 25 miles long, with transmission voltage of 22,000 volts, has only three points at which it is protected by lightning arresters. I was curious to know what had been the experience, and wrote to the operating engineer, Mr. D. W. Beldon, one of our members. He replied that the line had never been without current since it was started, last fall; that notwithstanding the fact that there had been many lightning storms, including one which occurred while the load was at its peak, there has never been any trouble at all from lightning. There is a discharge over the lightning arresters, but it has never been such as to interfere in the slightest manner with the operation of the line.

MR. A. J. WURTS:--I am pleased to note that Mr. Mershon does not recommend altogether abandoning the spark-gap lightning arrester.

I do not agree with him where he states that " this discharge will pass to earth by gradual leakage over the insulation of the system if the approach of the cloud is slow enough to give time for such leakage." I do not believe that the velocity of the cloud has any immediate influence on the static charges in overhead wires as to whether they leak to earth or become disruptive. I consider the cloud or upper storm strata and the earth to form the two terminals of a huge static machine and I think you will agree with me that a lightning discharge does not start from a single point but that the main discharge as we see it is made up of a large number of smaller tributary discharges which in turn are made up from still smaller sources, very much as our water sheds are ultimately concentrated into one large stream or river. I believe the same to be true in the earth terminal, that there also are tributary discharges from all sources of electrostatic capacity and from all directions toward the main stroke. I believe that all electric wires, grounded or otherwise, car rails, gas pipes, water pipes, all form a part of the earth terminal of this huge static machine and that a grounded wire in the neighborhood of an insulated electric line will not materially protect that line but that all will discharge alike and that the discharge will tend to be disruptive with every discharge of the the static machine—with every stroke of lightning. If there is any virtue in the theory of the leakage of the static charge, surely this ought to manifest itself in our trolley wires, all of which are thoroughly well grounded as far as leakage is concerned, although for disruptive discharges it is admitted that the ground connection is of no avail, owing to the large inductive resistance intervening between the overhead wire and the ground connection.

I am sure you all know that wire fences, gas pipes, and even gilt mouldings around a room will give off discharges during a thunder storm, and these discharges, as I take it, are due to the release of the electric stress by the lightning discharge breaking through the dielectric. The charge then which had previously existed in all bodies having electrostatic capacity, seeks to establish a path to the main lightning discharge; so that every piece of metal, every conductor, whether " grounded " or otherwise adds to the capacity of the earth terminal. I have even noticed discharges between parts of large steel buildings.

Admitting now that discharges do occur from all kinds of conductors, it would appear that the overhead grounded wire could hardly be considered a reliable source of protection because if it really did protect, I do not believe that we would obtain sparks from the inside metallic parts of buildings, protected (?) as they are by well grounded water pipes, forming the best possible overhead grounded wire.

MR. THOMAS:—I do not know of results where all the conditions have been carefully investigated and where it is definitely known that there has been trouble without a grounded wire, that it has been stopped by the addition of a grounded wire, and (to make the proof of the efficiency of a grounded wire complete) we should have also the other case, where the removal of the grounded wire shows the beginning of trouble again. Such a case would be very unlikely and in its absence we must wait for a very large number of ordinary tests.

In regard to Mr. Mershon's assumption as to the nature of the effect of lightning upon the line, he concludes that it is practically all electrostatic induction, but I believe he is hardly justified in neglecting the electromagnetic entirely.

In discharges which come to the ground in the immediate neighborhood of the line, we certainly cannot neglect the electromagnetic effects. The difficulty of protecting oil tanks and powder magazines even with a considerable amount of grounded conductor in the neighborhood is also well known.

Dr. Perrine has spoken of the losses on grounded wires close to transmission lines. I am surprised to find that it does not amount to anything. I should think it probably would be considerable, and if the grounded wire is made of considerable conducting power, *i.e.*. low ohmic resistance, I imagine there will be found quite a little loss; and more than that, if these grounded wires are placed close to the transmission line, as must be done to get effectiveness, it must considerably increase the electrostatic capacity of the system. This might be a serious item in a large plant. The problem is very complex and I think we should go very slow in staking too much on grounded wires.

Another point on which I think Mr. Hayward can give us some information—it is generally supposed that the striking of the lightning to the ground is the most harmful feature. I am inclined to believe that the discharge within the cloud in a more or less horizontal direction will produce a much more destructive effect upon a transmission line which happens to lie somewhere near parallel to the line of this discharge than a vertical discharge will.

Dr. Perrine:—I would like to speak a word, Mr. President, in explanation. I see Mr. Thomas has distorted my statement that I could not find a loss, to the statement that I found no loss. There is a good deal of difference between the two. The matter is difficult to measure. I tried to measure it, and couldn't find it. I didn't say it wasn't there.

Then there is another point that I want to call attention to now that I think this discussion is getting a little mixed on, and that is, that there are two things to protect against. One is the gradual charge and discharge of the line due to conditions of the atmosphere, and it may be that a line is at a high potential at one part of the country and at a low potential at another, or that the line is gradually acquiring a charge from the wind blowing over the line when there is no lightning in the neighborhood, and in perfectly clear weather you can have that. It is against this form of trouble that I believe that the guard wire is of most advantage. I do not believe that the guard wire is of any very great advantage when you have lightning discharges of severe character. There you do get, as both Mr. Wurts and Mr. Thomas have stated, an electromagnetic effect as well as electrostatic but the gradual charge and discharge of a line that would come in perfectly clear weather is a very nasty thing, and, as I said, one line that I saw myself, 46 miles long, which Mr. Mason was handling with me, was the only line, as Mr. Mason remarked, that he ever succeeded in taking hold of when there was no dynamo connected with it, in dry weather, without getting a shock. He attributed that almost entirely to the protection of the neighboring grounded wire.

Dr. A. E. Kennelly:—This is a very interesting and important subject and one that must always be of great practical consequence, because it is one of the standing difficulties in our transmission line work. We can protect against the regular difficulties, but lightning is one of the difficulties that cannot be reckoned with. Experience in this matter extends to a much earlier date than is generally supposed, because in a certain sense we have experience on this question for at least 50 years, in the protection of telegraph and telephone wires. It is true that the effects of lightning in telegraphy are of much less consequence than in a power transmission system, because the amount of property that may be damaged in telegraphy by a lightning stroke is comparatively small. Nevertheless, the experience which can be accumulated on the long wires in telegraphy bears upon the experience which we seek to accumulate in the protection of transmission lines. It has been a popular impression derived from many years' experience in telegraphy that the presence of neighboring overhead wires does protect against indirect lightning effects. Of course, we know that when we speak of the direct flash nothing can afford protection, but in regard to these surges due to lightning discharges in the vicinity, there is a strong popular belief among telegraphists, that neighboring wires do protect. If we know anything at all about lightning—and we do not know very much—it is that when we put a conductor wire under ground, or in an electrical conducting shell, that the buried wire is freed from electrostatic disturbances, and also, to a certain extent, freed from electromagnetic disturbances. We all believe that a buried wire, disconnected from all apparatus, is in no danger of a lightning stroke, induced or otherwise. When grounded wires are carried over and above, or in the neighborhood of, a working wire, the earth is virtually raised over that wire, or in the vicinity of that wire, and we partially produce that effect which a completely buried wire more thoroughly attains. I think, therefore, it stands to reason, that if only there are grounded wires enough over and above and around a working wire, immunity from indirect lightning surges is brought to that wire. But whether it is worth while incurring the expense and trouble of stringing the grounded wires around the working wire is another and a different question. Some years ago I had occasion to collect some information of this character from the representatives of local stations, and I found the evidence was somewhat in favor of protection by means of guard wires suspended in the neighborhood of the working wires.

The question of electrostatic capacity and its increases due to grounded wires on the working wires, is one of the minor considerations to be taken into account, but after there are three wires up in a three-phase overhead system, the extra capacity that can be given by adding other wires is comparatively trivial. It is the first extra wire that counts, and when you have several wires up together side-by-side it would not seem that the electrostatic difficulty is going to be a serious one. The amount of energy which may be wasted, in transformer fashion, from the main line to the loops of the grounded lines as secondary circuits, is also a matter to be considered, and I do not think that it has been worked out. It would seem, therefore, that there is an advantage, theoretically at least, in having grounded wires around working wires, but the disadvantage of having to string extra wires around a transmission system is very serious.

MR. LINCOLN: —Mention has been made of the electromagnetic as well as the electrostatic effect. I wish to call attention to the fact that these grounded wires are to a certain extent a protection against electromagnetic as well as electrostatic effect of a lightning discharge in the neighborhood of the transmission line. The grounded wires constitute a short-circuited secondary and the induced effects from the lightning discharge in the neighborhood will be largely absorbed by that short-circuited secondary. In a solid metallic conductor you can get no electromagnetic effect; so the ground wires may approach that condition.

One other point which has been brought out before, is in regard to the discharge by the grounded wires of the atmosphere which blows across the line. Mr. Mershon does not treat of that in his contribution, but I think it is an important point. In this climate we do not get that effect so much as in the West, because the atmosphere here contains much more moisture.

Mr. F. S. Woodward:—I would like to speak of just one practical point in regard to barbed wires on a line that I am familiar with. For about two years after erection they remained in good condition, then began a series of breaks due to rusting. Nearly every break of a barb wire was followed by a short circuit in line wires. As a result of this experience the barb wires were replaced with No. 4 B. & S. iron wires. The extra cost of larger size iron wires was more than offset by lesser cost of erecting.

This line had ground wires every six poles. The ground wires were brought about half-way up the pole and then divided, passing up at extreme end of cross-arms. This to some extent protected linemen when at work, as otherwise they were in contact with the ground return.

Mr. Rushmore: There is one point which I have not heard mentioned. If a transmission line runs through a mountainous country where a considerable difference in latitude exists between different parts of the line, there will be an electrical effect, due apparently to the difference in altitude which causes a much greater difference of potential between wires and ground in the low than in the high altitudes. In some instances it is known that a considerable difference of potential exists between the base and summit of mountains. A grounded wire strung along the line should be of assistance in the prevention of trouble from this cause.

Mr. R. S. Kelsch:—The Lachine Rapids Hydraulic and Land Co., Ltd., of Montreal, Can., operating a general overhead distributing system for light and power work, at 2200 volts three-phase, has experienced considerable trouble and suffered damage to transformers principally, from lightning.

When this company began operating, there were five telegraph, telephone and electric light companies operating in the city of Montreal—which compelled the Lachine Rapids Company to construct 95 per cent. of their lines below the lines of other companies. A careful record kept of the eighteen circuits indicated that the greatest amount of trouble, such as transformer burn-outs, etc., caused by lightning, occurred on the circuits that were built under the lines of other companies. When this record was started, it was supposed that the circuits running into the open districts where there were no wires above them, would show the greatest number of transformer burn-outs, etc., but the result was just the reverse.

Mr. John F. Kelly:—I believe that the main protective effect of the grounded wire is not against lightning discharges, but principally against the ordinary atmospheric electricity. We all know that with a difference of a few yards in elevation we may find a difference of several thousand volts, and a wire suspended at any distance above the earth will in time gain the same potential as the air or bring the air to its potential. The charge so accumulated on a wire will discharge to earth when the conditions are favorable, the most favorable place being usually determined by the weaknesses in transformers and dynamos. As to the accumulation of that charge, the rate at which it accumulates, I remember in the old telegraph days, before the dynamo service was much developed, in western New Jersey, in the hill country there ran a telegraph line through a tunnel, and was protected by lightning arresters. Well, they couldn't put in lightning arresters fast enough 20 years ago to keep that line in service. There was trouble in calm weather, when there was no sign of disturbance in the neighborhood at all. Then, when the alternating current service was first introduced, I remember watching a line in the hills of Connecticut. The sparking on the lightning arresters was constant on account of the atmospheric charge even in fine weather, although the line was only a few miles long. The circuit-breaker, in connection with the lightning arrester, was high chattering all the time. Now, I think it is against electricity of that nature that the grounded wire is of service, if it is of any service at all.

The most important point in Mr. Mershon's paper, to my mind, is that, if his theory is correct, the grounded wire may be placed below and yet be equally as protective as if placed above. No one heretofore has attributed any protective effect to the grounded wires when below the working conductors. The great danger in even laying it heretofore has been, that being above, in breaking, it would fall on the transmission wires.

But as to how much protective effect it really has, I think there is considerable doubt. Mr. Mershon has referred to one line on which it appears to protect perfectly. I think I recognize the line, and on that line there are a lot of water crossings, the ærial line at each crossing being replaced by a sub-aqueous cable, and at each of these crossings both sides are protected by lightning arresters. So that is one thing, The other thing is difference in elevation between the two ends of the line. The effect of hilly country, to which Mr. Rushmore alluded, is not very pronounced there. And the third thing is that they never have run without the grounded wire. On the other hand, I know of a plant in the south where they have put in grounded wires and then grounded them as often as they could. It is, however, a pretty bad country to obtain good grounds in as the clay soil takes hold deep down in the dry season. A number of the grounds have been made in water courses and some have been kept artificially wet, but I think they have not been able to find any improvement whatever. My own feeling is that while there is some protective effect from the grounded wire, that it doesn't pay for the complications.

It has been said that the electrostatic effect on the working conductors is of no importance, but I think when you get lines 150 or 200 miles long with a very high voltage and ordinary frequencies, it becomes highly important, especially if one uses a single grounded wire not set in neutral position. I have never seen a grounded wire so placed. If it is set out of the neutral position it will affect not only the amount of electrostatic line charge but it will affect its distribution, so that the flow will be different on the three legs of the line. The disturbing effects of a balanced electrostatic charge are bad enough.

In the seventh edition of Culley's Handbook of Practical Telegraphy, p. 126, the use of individual ground wires on the poles, not connected by an overhead conductor, is described. Several able telegraph engineers have told me that this type of line construction has given them the same protection in nature and amount that the overhead grounded conductor is said to afford. Obviously, Mr. Mershon's condenser theory cannot apply here, and in consequence, these observations tend to throw doubt on the completeness of the theory.

MR. HAYWARD:—I wish to suggest to the Committee on High-Tension Transmission, that they send out word to every operating engineer; to everybody who has any stations of high-tension lines under his charge, and ask that every one of their engineers operating under them be made an observer; to have everybody working under them make careful observations, not only when the storm is on but when the storm is coming, as to what happens —time it as nearly as possible, record it in a log book. In the case of a breakdown from lightning, let him go right to the spot as if it were a fire, and let him collect the evidence right then and there, and at the end of a year or two we shall all know far much more about this lightning question than we know to-day.

I think that the location, other than the elevation,—the nature of the ground—has a great deal to do with lightning discharges. I think where you have a broad valley and your lines are lying in the valley near the base of a mountain, that you will get discharges which on the average are quite different.

Our system embraces 20,000 volts and some 400 or 500 miles of high-tension circuit spreading over a country that is about 150 miles long. Starting in the old days when the insulation was low, with 2000 volts, when all the wires were in the trees, we never knew any lightning trouble in any shape. As we improved our installation our lightning troubles came on us more and more, and now, carrying 20,000 volts, with lines thoroughly insulated, we know what lightning means. I do think that overhead grounded wires, such as telephone and telegraph wires, are a protection, for this reason, that I have never lost a transformer in our business section which is the most thickly covered with other wires. But they are not complete protection by any means, even at 2000 volts, for although our lines at Salt Lake City are almost all on the same poles as the telephone wires, yet the telephone wires do not entirely protect them. At the same time, we cannot help feeling that if you absolutely surround your wires with a grounded network, that they must be protected, except against perhaps some great stroke of lightning, so to speak. However, that is absolutely impracticable from our point of view. We have had many and many an instance where there has been a sudden discharge of lightning, and almost instantaneously, or immediately following, there has been a jump from the lead outside the transformer to the case of the transformer, rather than going through the transformer coil. We have had a lightning discharge smash up the insulators on the line, cut into the station, jump from the lead coming from a transformer from 16,000 volts, cut off the transformer and the puncture papers in the lightning arresters never show any discharge. Now, all those occurrences which we have all show the same sort of effect. Our troubles come at the moment when the lightning discharges. Troubles due to the raising of the potential of the line when there is a dust storm, or wind storm or a thunder cloud, are taken care of on the lightning arrester. I have never heard or known of any trouble from that. Every single occurrence that has ever given us any trouble has been at the moment of the lightning discharge.

MR. JOHN F. KELLY:—Mr. Hayward, I think, is probably right as to his having no trouble on very high-tension lines from atmospheric electricity, but the conditions are very different on lines of moderate-tension or low-tension, like telegraph wires. On a high-tension line the voltage with which one is sealing on the line is itself of a magnitude comparable with the atmospheric difference of potential discharge, and consequently when the dielectric strength is made sufficient to resist the puncturing of the insulating material, puncture by the charge accumulated by the wires is also presumably guarded against. But on low-tension circuits, where the normal voltage is much below the difference of potential that may arise from atmospheric charge there is no such guard against atmospheric effects.

PRESIDENT SCOTT:—Mr. Hayward has the difficulties which come to engineers through coöperation. He is trying to coöperate some three or four different plants in different places and in different directions from Salt Lake City, and which have been laid out with different voltages and under different conditions, as separate independent plants entirely,—the old Pioneer plant at Ogden, the Utah Power Company, the big Cottonwood, and now, I believe, he is linked in with the Telluride Power Transmission Company. Is there any further discussion?

MR. W. L. WATERS:—I did not quite follow Mr. Mershon's theoretical calculation, but I would like to suggest an alternative calculation, which has the advantage, from my point of view, that gives results which agree more with my own practical experience.

Let us assume that a cloud has just discharged, and that we are left with an induced charge on the transmission wire which raises this wire to a high potential above the earth, and we wish to find out to what extent the presence of a grounded wire will lower this potential. The system which we have to consider consists of the transmission wire B, carrying a charge Q_1, the grounded wire A, carrying an induced charge Q_2, and the earth G, also carrying an induced charge. For the purpose of calculation, the earth can be considered as an infinite conducting plane, and by Lord Kelvin's theory of electric images the distribution of electricity induced on the surface of the earth can be replaced by charges $-Q_1$ at C, which is the image of B, and $-Q_2$ at D, which is the image of A. Then we have for the potential of wire A

$$(1) \qquad V_2 = p_{ab}Q_1 + p_{aa}Q_2 - p_{ac}Q_1 - p_{ad}Q_2$$

where p_{ba}, p_{ac}, etc., are Maxwell's coefficients of potential. And assuming that the diameter of the wries is infinitely small compared to the distance between them, these are given by the expression,

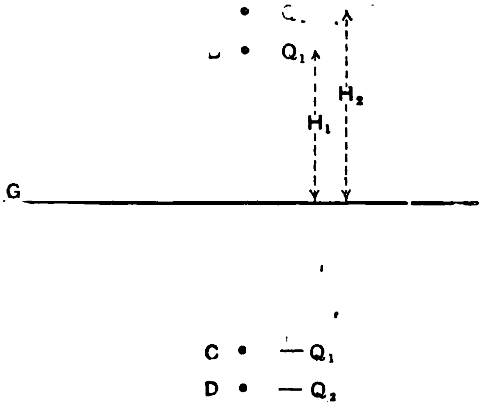
$$p = -2 \log r$$

where r is the distance from the center of one wire to the center of the other.

But as the wire A is grounded its potential V_2 is zero. Thus putting $V_2 = 0$ in equation (1) and solving for Q_2 we get

$$Q_2 = Q_1 \frac{\log \dfrac{H_2 - H_1}{H_2 + H_1}}{\log \dfrac{4H_2}{d}}$$

where d is the diameter of the wires.



Similarly, we have for V_1 the potential of the transimssion wire B.

$$V_1 = p_{bb}Q_1 + p_{ab}Q_2 - p_{bc}Q_1 - p_{bd}Q_2$$

substituting for Q_2 in terms of Q_1, and evaluating we get

$$V_1 = 2\,Q_1 \left\{ \log \frac{4\,H_1}{d} - \frac{\left(\log \dfrac{H_2 - H_1}{H_2 + H_1}\right)^2}{\log \dfrac{4\,H_2}{d}} \right\}$$

Assuming the ground wire not present this becomes:

$$\overline{V_1} = 2\,Q_1 \log \frac{4\,H_1}{d}$$

so we get as the value for the shielding effect:

$$\frac{\overline{V_1} - V_1}{\overline{V_1}} = \frac{\left(\log \dfrac{H_2 - H_1}{H_2 + H_1}\right)^2}{\log \dfrac{4\,H_2}{d} \cdot \log \dfrac{4\,H_1}{d}}$$

Taking the numerical value used by Mr. Mershon, *i.e.*, No. 00 wires 12 inches apart, and taking the height above the ground as 30 feet, we get the shielding to be 25 per cent. Taking what perhaps is a more practical case, No. 4 wires 24 inches apart, we get the shielding to be 14 per cent., which is rather different from Mr. Mershon's result.

But I think that a theoretical discussion of this subject is not very much to the point, because we really know very little about the conditions in the phenomena which we are discussing. It is also extremely difficult to get any reliable practical information as regards the effect of the ground wire because unless we do as Mr. Thomas has suggested, *i.e.*, try a number of transmission lines both with and without a ground wire, we cannot really get any definite information. The fact that one transmission line is satisfactory without a ground wire and a second one is also satisfactory with a ground wire gives us no really definite information.

My own experience has been confined to European conditions, *i.e.*, short mountain lines worked at 5,000 to 10,000 volts. The conditions under which they work are violent lightning storms, and heavy sleet and snow storms during certain seasons of the year. The sleet and snow storms very often bring down the ground wire, producing a short circuit, and the screening effect of the ground wire does not seem to be very appreciable in a lightning storm. So that the general opinion of operating engineers is that the ground wire is far more trouble than it is worth.

MR. CURTIS:—In this discussion I notice that several gentlemen have referred to the failure of telephone lines located above power leads to protect the latter from lightning or electrostatic induction. When we take into consideration the fact that modern telephone lines are composed of metallic circuits almost exclusively and are not grounded, their failure in this respect hardly seems strange, and further if they actually *do* afford the slightest shielding action it must be accounted for by some other theory than that pertaining to grounded wires. I believe the same statement is practically true of telegraph circuits, which are rounded normally only at their extremities, which would render them ineffective owing to conductor resistance, except for exceedingly short distances from their terminals. I have known long metallic telephone circuits, with clear weather prevailing their entire length and breadth, to give off electrostatic discharges sufficiently severe to destroy the coils connected to them, the current of course seeking the shortest path to ground.

Professor D. C. Jackson:—The problem which exists with respect to protecting a line from sparking to ground or surrounding parts, no matter what the cause, is to keep the line as nearly as possible at the same electrostatic potential as the ground. Now undoubtedly the grounded guard wire does something in that direction, and Mr. Mershon is right in making his computation and saying that there is some effect from the guard wire; but on the other hand, he has not taken data of such a form and of such numerical values as to give results that may be considered to be always applicable, or adaptable to commercial conditions in a long and important transmission line. For instance, the guard wire in Mr. Mershon's example is taken too close to the line wire, and since the protective effect is dependent upon the logarithm, as the guard wire gets further away from the line the falling off of the protection is enormously rapid. I therefore think Mr. Mershon is misleading us by taking his one foot distance; he is exaggerating the effect.

There is another element that Mr. Mershon has omitted, which has a great deal of influence. You must bear in mind that if one has an induced discharge upon a transmission line and guard wire due to a cloud overhead, and that cloud discharges into a cloud at some distance, or discharges to earth, there is an almost *instantaneous* change of the potential of the earth under the line at certain points and also of the atmosphere surrounding the guard wire. The resistance of the guard wire, its inductance and capacity enter to modify the instantaneous change of the charge in the guard wire itself and consequently the guard wire during this period (because of resistance, self-inductance and capacity), is unable to exert its full influence to protect the line wire; and Mr. Mershon has omitted to introduce the effects of the self inductance and capacity and resistance of the guard wire and its ground connections into his formula. I think that he has omitted them because they cannot yet be put in, for the reason that we do not have a reasonable knowledge of their values under the conditions and therefore have no way of representing them in the formulas. So I say Mr. Mershon is right in presenting the matter as he has, but he is without question exaggerating the effect of the guard wires, and very largely exaggerating it, when he says that it may be expected to afford a protection of something like 70 per cent. I think if this was taken at 7 per cent. or 7/10 of 1 per cent., it perhaps would come nearer the truth.

MR. MERSHON:—I think that in general I agree with Professor Jackson—but I would like to take up one or two points in connection with what he has said.

As regards the theory of the matter, I agree pretty thoroughly with Professor Jackson. I will not commit myself too far, however, in that regard. As regards what Mr. Waters has said, I made an assumption in treating this matter, on purpose to keep the problem simple. I assumed that the space potential at each of the two wires was the same. I think if the wires are in the same horizontal plane it is a pretty fair assumption, and this is the relative position which most frequently has place in practice.

As regards the size and distance between wires, I am not so very far wrong. If I remember rightly, the distance I have taken as between the wires is exactly that which existed on a line on which it was claimed the ground would give very good protection. The size, also, was approximately that which I have taken; for barbed wire was used whose effective size, because of the twisted strands, is considerably greater than a single wire of an equivalent section. For most cases in practice I think the figures I have given furnish a fair sort of criterion. I have purposely avoided the questions of oscillatory effect, of self-induction and all those complicated questions which require elaborate assumptions of questionable accuracy.

It seems to me that the question of electromagnetic action is one of amperes and frequency, and not of volts, as Mr. Thomas has stated, and it is hardly conceivable to me that the currents at the distances that flashes often occur would be great enough to affect the line seriously from electromagnetic action.

Now, as regards the position of the cloud, that changes the problem to some extent, but I do not think it changes it altogether. The shielding action, even if the cloud is affecting only part of the line, would have place to a considerable extent.

As regards the discharge of the atmosphere itself—suppose the particles of air or moisture around the wire are charged, isn't it likely that the effect of the inductive action due to the great mass of particles beyond the wire will be considerably greater than that of simple leakage from those particles to the wire, if there is such a leakage effect? The flash between clouds, it seems to me, does not alter the problem so very materially. You have the effect there of a redistribution of charge, and you still have to a considerable extent the shielding action of the grounded wire.

As regards the difference in altitude, I have gotten the altitude effects in a great many cases and it never seemed to me necessary to explain them by leakage from the atmosphere. Simply because you cannot see a cloud, is no proof that it does not exist. The cloud need not necessarily be a mass of moisture; it may be air under some condition differing from that of the surrounding air; so that in considering a charged cloud, we should consider any mass, whether it be moisture or whether it be air of a different density from the air around it, and which might accumulate a charge on the surface of separation between it and the surrounding air.

As regards protection from electromagnetic effects, if there are any, the resistance of the ordinary grounded wire would be too high, and the self-induction too high, to furnish much protection, especially as you cannot conveniently ground the wire any oftener than at each pole.

As regards the gathering of data, the grounded wire is taken up in the lists which the Transmission Committee are sending out, many of which are coming back filled in. We should be only too glad to get the minute attention to the subject of lightning protection, as well as other points taken up by these lists, that Mr. Hayward advocates, and we shall certainly expect to get a fine lot of data from Mr. Hayward's plants.

Mr. W. J. Hammer:—Last fall I had the pleasure of spending some days investigating the Valtellina 20,000 volt, 3-phase Railroad in Italy constructed by Messrs. Ganz & Co., of Budapest, Hungary.

I remember that one of the methods of protection used was a drain pipe filled with water, which acted as a water resistance, and which was connected to the wires and to the ground, the intention being that while there would be ordinarily no leakage, when lightning passed over the circuit these would act as a protective device. The main reliance, however, was placed on a form of lightning arrester which by its simplicity commended itself strongly to me. I understand that since these have been put in place no lightning has ever entered the power-house, and it is claimed that there is no necessity for lightning arresters inside of the power-house.

The device, which was placed just outside the power-house, consisted of three funnels, one attached to each of the 3-phase circuits, being supported by porcelain insulators. Underneath each funnel is a little spray of water which is thrown up so that it is a short distance from the funnel, but not making contact therewith. Should any abnormal voltage appear on the line due to lightning it is carried off by the jets of water.

Mr. W. A. Blanck:—I will state that in most of the Italian and German high-tension lines lightning arresters are used only in power stations and substations and seldom on the line itself. The use of iron such as barbed wire along the line for protection of the same from lightning has been abandoned.

The lightning arresters mentioned by Mr. Hammer are used on the Valtellina Railroad in northern Italy and consist of a small reservoir which furnishes constantly dripping water to the various wires of the high tension system. The small drops of water upon reaching the wires are charged and upon leaving them carry off this charge and in this way very satisfactory results are obtained.

Mr. Mershon:—I would like to hear from Dr. Perrine and some of the other members who have spoken of the losses due to a grounded wire as to how that loss could occur and as to the nature of it. Do they mean atmospheric loss. It seems to me that with grounded wires, especially if the neutral of your system is grounded and you have between the grounded wires and the line wires anything like the distance there is between line wires themselves, you will not get much loss. For you are then concerned with a voltage a great deal lower than that between the line wires and you presumably keep the atmospheric loss between them pretty well down.

Mr. Mailloux:—I want to caution Mr. Mershon, in his statement about the loss due to electromagnetic effect caused in the parasitic circuits, constituted by the grounded sections. He says that the resistance of these segments would be a protection against loss. I think that there is a certain resistance at which that loss will be the maximum. If we have an infinitely great resistance, of course we would have an e.m.f. there, but no current. With an infinitely small resistance we would have a reactance loop in which you would have a full counter e.m.f. effect and very little loss excepting the small $I^2 R$ loss necessary to keep the large current flowing; but there is between those extremes a critical resistance which corresponds to the maximum loss. Evidently, we only have a differential e.m.f. due to the difference between the electromagnetic effects of the three wires. If the conducting wire could be placed in the center of the triangle perhaps the resultant effect would be negligible anyway.

President Scott:—The paper we will take up now is: " On the Testing of Electrical Apparatus for Dielectric Strength." by P. H. Thomas.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, July 1st, 1903.

THE TESTING OF ELECTRICAL APPARATUS FOR DIELECTRIC STRENGTH.

BY P. H. THOMAS.

It is evidently very desirable before depending upon apparatus for commercial service, to have assurance that it is in proper operating condition and also, where the apparatus is built to specification, that the specification has been met. The only practical method of determining the condition of the apparatus as regards its insulation is by means of over-potential tests. *Potential tests have been used for a number of years and have been found to be in general quite satisfactory.* However, in common with all types of tests which depend upon the application of abnormal strains, over potential tests have certain drawbacks and involve certain risks. A brief discussion of such objections, especially in regard to insulation tests upon very high tension apparatus, will be found in the following pages.

(1) A disruptive test fails partially of its object in testing the fitness of the apparatus for actual service, because the conditions of the test do not approximate closely the conditions of the service, either normal or emergency conditions.

(2) Serious injury may be done to the insulation of the apparatus by the test, even under apparently favorable conditions, so that failure may result afterwards in actual service.

(3) In making tests on finished apparatus, it is impossible to test each portion of the insulation separately and the result of many types and forms of insulation being coupled together, is that only that which is weakest with regard to the particular conditions existing at time of test will be tested.

(4) In general, electrical apparatus is never in a condition so poorly adapted to stand dielectric strains as when first installed.

(5) Insulation tests require special testing apparatus and expert and *experienced* direction which are very often not available, and without which great risk is run in attempting such tests.

(6) As an exception to the above (paragraph 5) it is evident that some simple types of apparatus, such as insulators, high tension bus bar insulation, high tension series transformers, etc., may be readily tested without great danger.

(7) Fuller consideration of paragraph (1). Potential strains upon dielectrics cause effects of two kinds:

(*a*) A constant tendency to puncture the dielectric, which is caused directly by the presence of the potential and depends on the physical dimensions and nature of the dielectric, and which probably remains constant as long as conditions are unchanged; *e.g.*, physical or chemical state. This strain is almost mechanical in its nature.

(*b*) A tendency to heat or produce chemical change in the dielectric, largely the former. This heating also is caused by the voltage and is very much more marked with alternating current than with direct current. Though comparatively small in actual amount, this generation of heat is a dangerous thing, as it occurs within the body of the insulating material which is usually a poor conductor of heat.

As insulation heats up, it becomes much less able to withstand the strain described in paragraph (*a*) above, and, further, the rate of generation of heat within the insulation itself becomes much greater. As a net result, if insulation under strain once reaches a sufficiently high temperature, it is practically certain to get hotter and hotter and ultimately to break down. In other words for continuous running it is necessary that the heat generated by the potential in the dielectric be dissipated as fast as generated. In tests of actual apparatus, the critical rise of temperature may be reached in as short a time as one-tenth of a second in some cases, or in other cases perhaps only after a long time, perhaps an hour. As long a time as an hour would be required only in large bodies of insulating material; *e.g.*, in large capacity or high-tension apparatus.

Different kinds of insulating material are affected by the strains described under (*a*) and (*b*) in very different degrees. Gaseous dielectrics suffer substantially no heating, while solids and liquids usually have their breaking-down strength determined by this heat factor.

In actual service, injuries to electrical apparatus usually result from overheating, dirt, moisture, chemical exposure, mechanical injury or wear due to vibration and occasionally a strain from lightning or over-potential stress. The latter strains, however, are rarely extremely severe, except as they may cause local concentration of potential in the windings of apparatus, as will be discussed later.

Thus the volage time test, which is usually applied to finished electric apparatus, by no means reproduces all the conditions of actual service. On the other hand, it is of course true that apparatus which will stand a high disruptive test will usually stand better in service, so that such a test is of value.

If a high disruptive test is relied upon by a purchaser to determine the acceptance of apparatus and to terminate responsibility on the part of the manufacturer, the latter will be tempted to design his insulation in such a manner as best to stand the disruptive test at the sacrifice of some features more valuable for preventing deterioration in actual service. This difficulty becomes a very serious one where unusually severe disruptive tests are specified in a contract.

(8) Fuller consideration of paragraph (2). With low-tension apparatus, little or no harm is to be expected from reasonable over-potential tests carefully made, provided insulation is in good condition. An exception should perhaps be made of dangers of local concentration of strain in high tension generators or motors of small size, as will be explained later. The following discussion applies to high tension apparatus chiefly.

The amount of heat generated within the body of a dielectric increases at least as fast as the square of the voltage. Further, this loss, with constant voltage, may be increased several times by an increase of 100° C. in temperature. This means that a strain of double potential continued for any length of time strains the solid insulating material far beyond any condition it will meet in service. Further, the ability to stand the strain will be determined rather by the facility for getting rid of the heat, which is usually of little consequence in commercial work than by other features of the insulation more desirable for actual service; further, the hottest part of the insulation will be inside, so that the center portion of the material may be badly charred, while the outer portion, the only part visible to the eye, has been kept cool and appears uninjured. This means that very serious injury to high tension apparatus may be entirely beyond the possibility of detection until further developed by actual service.

Potential strains above a certain critical point cause a tendency for brush discharge over any insulating surface. If continued, this will deteriorate the insulation so that a discharge may continue afterwards at a lower voltage. This effect will occur even under oil, and, like the internal heat, will not be visible to the eye until in a very advanced stage.

When a coil is charged to a high potential and one end is suddenly discharged, there is a strain equal as a maximum to the full value of the discharge voltage, tending to cause the charge upon the turns of the coil to jump to the terminal through the insulation across the turns rather than pass around these turns. Since this total " discharge voltage " may be the abnormal voltage at which the apparatus is being tested and since this abnormal strain may be concentrated on a portion of one coil, where many coils are used to withstand the normal voltage of the circuit, it is evident that certain turns of the coil (which lie next to the terminal which is being discharged) will receive excessive strain. The condition which is essential to produce this concentration is that the discharge of the terminal of the coil shall be extremely sudden. This can usually occur only when the terminal is discharged by a spark close to the terminal itself, electrically speaking, *e.g.*: any accidental or other discharge between the wires used in applying the test, or in the apparatus itself, will tend to puncture insulation between turns at certain points within the winding. Such injury will oftentimes not be discovered, as the apparatus being tested is not in a condition to show a short circuit when it is not connected to a generator. This danger is very serious with extremely high voltages. Apparatus may be protected against this strain by the use of choke coils, or high resistances, or static interrupters in the leads of the apparatus to be protected, provided no discharge occurs nearer the apparatus than the protective device. In this connection it should be noted that if the spark gap is used as an auxiliary to measure the potential of the test, satisfactory means must be used to prevent a dischagre on the spark gap from causing injury to the apparatus being tested.

The emphasis placed upon this particular phenomenon is not for theoretical reasons only, but because, in a number of actual cases, serious injury has resulted to apparatus therefrom. Furthermore, such conditions have been reproduceed for purposes of investigation.

(9) Fuller consideration of paragraph (3).

In testing finished apparatus, it is manifestly impracticable to subdivide the windings into more than a very limited number of parts, *e.g.*: in case of the transformer, into more than possibly four parts. When such a portion is subjected to disruptive tests, a breakdown may evidently occur in a number of ways, *e.g.*: between portions insulated only by air distances; over a surface of insulating material, which may be marble on terminal block, fibrous material or possibly the surface of oil in an oil insulated piece of apparatus. Furthermore, breakdown may occur through solid material, which in some places will be well ventilated and in other places will not be well ventilated. Sometimes portions of this material which in the disruptive test receives full strain, may when running in commercial service be so located as practically to receive a very much less strain. Such a point, for instance, would be the neutral point of a three phase, star wound generator. It is thus clear that if the severity of a test (as it must necessarily be) is determined by the strength of the insulation of the weakest spot of these various types and qualities of insulation, the other parts will receive an insufficient test. It may occur that a portion of the insulation less likely to give trouble in subsequent service will be this weakest portion, and will determine the whole test, leaving the condition of the other more vital portions of the insulation insufficiently tested.

(10) Fuller discussion of paragraph (5).

In tests made by persons inexperienced in such matters, there is grave danger of injury to apparatus which would not result when tests are properly made. Such difficulty may arise by the use of testing apparatus having too high an inductive factor or field reaction, so that current to the apparatus may either raise the voltage beyond the usual ratio or so deform the e.m.f. wave as to cause an excessive strain; or by making tests when insulation is not in good condition; or in preliminary trials, in allowing tests to be on too long, though perhaps at a slightly lower voltage than the voltage of final test; or by improperly determining the temperature of the apparatus; or in a number of other ways unnecessary to enumerate. Difficulty from this source is by no means of rare occurrence, and it is very difficult to avoid in large high tension apparatus.

(11) Precautions to be observed in testing.

The most important precautions to be observed in making disruptive tests are here summarized:

(*a*) Insulation of all apparatus to be tested should be definitely known to be thoroughly dry.

(*b*) All insulation surfaces and the apparatus in general should be clean and free from all kinds of foreign matter.

(*c*) The measurement of the insulation resistance will sometimes give an idea of the fitness of the insulation for test. This condition will usually be determined not by the absolute value of the insulation resistance, but by a curve of the variation of insulation resistance as the apparatus is being dried out. When it has been increasing for a period and finally becomes steady with steady temperature, the drying operation is probably fairly complete. *However, where air or oil spaces are included in the bulk of the insulating parts, these spaces may determine the insulation resistance so that no indication is given of the condition of the actual solid material.*

(*d*) Before applying a disruptive test, it should be definitely determined that the temperature of no part of the apparatus to be tested is above that at which the test is to be made remembering that tests of apparatus when hot, especially when very hot, are extremely severe.

(*e*) Electrical apparatus of large capacity, which necessarily contains considerable masses of iron and copper, lags behind the atmosphere in temperature changes, consequently when the atmosphere is damp and warmer than the apparatus, there is a tendency for the latter to " sweat or condense moisture upon its surface. This moisture will at least partially be absorbed by the insulation material and render the apparatus unfit for test; consequently, it is important in unpacking to open the packing case only when the air is cooler than the apparatus. *In case of oil-insulated apparatus, the insulation must be protected from moisture when once dried out until immersed ready for service.*

(*f*) The determination of the high-tension voltage actually reached during test is sometimes a difficult matter. The things to be avoided chiefly are the distortion of wave form or the change in ratio of transforming apparatus, or excessive drop due to the use of apparatus for applying the testing voltage, which is of insufficient size to supply the charging energy required by the apparatus to be tested. This subject deserves a full consideration, but has been so fully discussed elsewhere that further space will not be given here.

(*g*) In applying the potential of test to apparatus, the voltage should not be raised on the testing set to full value and then applied to the apparatus, but after being connected to the apparatus should be increased rapidly by small steps, or continuously from a voltage not over one-half the final value. Also, the voltage should be raised so quickly that the time during which the last 10 per cent. or 20 per cent. of the voltage is being applied will be short, as compared with the prescribed duration of the full potential test.

(*h*) To prevent local concentration of potential which results from any spark or break down occurring near the apparatus to be tested when the latter contains coils; choke-coils, static interrupters, or resistance in series with the terminal of the apparatus to be tested may be used. The result essential to the avoidance of this local strain is the prevention of the strain caused by the above mentioned breakdown from being transmitted without being smoothed out to the windings under test.

Evidently a choke coil in the lead of the apparatus will allow a change of potential to pass through it only slowly and if this coil be made to have several times the choking effect of the smallest portion of the winding to be protected (next the terminal) which is considered to be able to stand the voltage of the test momentarily, the necessary protection will be obtained. It would seem that a resistance in the place of the choke-coil would serve the same purpose and in a measure it undoubtedly will. However, since the resistance does not absorb voltage until after considerable current strength has been attained, it is not as well adapted to protect from sudden changes of potential as the choke-coil. The static interrupter being merely a choke-coil whose power is increased by the use of the condenser, will act in the same manner as the choke-coil described above. Usually, however, except where static interrupters are provided for other purposes, the choke-coil will be found more convenient.

(12) No complete recommendations are here made for specifications for testing apparatus for dielectric strength, but a few suggestions will be offered on topics in which there is probably a considerable diversity of opinion.

(*a*) In high-tension apparatus, *e.g.*: 20,000 volts and above, only moderate, short time, over voltage tests should be specified in contracts.

(*b*) Such tests should be made once for all when the apparatus is known to be in good condition, preferably at the factory, by experts, to give assurance that the specification has been met. Such tests should not be made a second time.

(*c*) After installation, a considerably lesser test should be made upon the apparatus, which will detect any serious injury in transportation and installation. Any moderate deterioration due to absorption of moisture, etc., will right itself with service, provided no abnormal deterioration has occurred.

(*d*) It is preferable to make high potential tests by increasing the voltage upon the apparatus as it is designed to operate, one terminal at a time remaining grounded, rather than making a high breakdown test by voltage from an external source.

(*e*) On tests of very high-tension apparatus, such as generators and transformers, no breakdown gap should be used in connection with the determination of voltage. Any error in the voltage of test, provided precautions as to the proper size of testing apparatus are used, will be comparatively unimportant. In some cases the voltage of the testing device may be determined by means of a spark-gap before the apparatus to be tested is connected to the circuit.

It must be borne in mind that in the above discussion only the objections to over-potential tests and the dangers to apparatus involved, have been considered; and that it is not recommended that disruptive tests be abolished. Such tests may be and regularly are made successfully and are very desirable to insure good insulation in electric apparatus and to determine the fulfilment of specifications. The point it is desired to emphasize is that great care should be taken to avoid injury to apparatus and that excessively severe tests, especially long-time tests at high-potential should be avoided.

Mr. L. A. Hawkins:—In regard to the use of choke coils for protective purposes in the leads between the testing set and the apparatus, although such coils are of value in preventing a destructive rush of current in case of the breaking down of the insulation of the apparatus, I do not think that their value is great as far as discharges outside of the apparatus are concerned. The testing set and the leads should be installed so that there can be no danger of an accidental discharge due to the breaking of the insulation of the testing set or leads. Consequently, unless a spark gap is used, there could be no discharges outside of the apparatus itself, in which case the choke coils would furnish no protection beyond that furnished by resistance in preventing destructive current flow in case of a breakdown of the apparatus. I believe that the best protection against puncturing of the insulation due to sudden discharge lies in sub-dividing the winding as much as possible and short circuiting the subdivisions by connecting both ends of each subdivision to the lead of the testing set.

I do not consider of much importance the objection raised in the paper that the weakest point is the only one tested. In practice it is the weakest point alone that is of importance. If that is strong enough to stand, the rest will take care of itself. Even in such cases as that cited, as in the coils adjacent to the neutral point in a three-phase grounded generator or transformer system, I believe that all the insulation should receive the full high-voltage test, for although under normal conditions the insulation of the parts near to the neutral point are subject to no high-voltage strain, nevertheless changing conditions of operation may necessitate a change in the connection of the apparatus, so that the part that was formerly at ground potential may receive the full line voltage.

As to the dangers introduced by the changes in voltage and wave-form in the testing set caused by the charging current, I believe that the best precaution is in employing a testing set of sufficient size relative to that of the apparatus to be tested, so that the charging current can have little effect on voltage or wave form.

I thoroughly agree with the statement that on tests of very high-tension apparatus no spark-gap should be used in connection with the determination of the voltage. I believe that the use of a spark-gap introduces danger to the apparatus and inaccuracy in the results of the test. Especially when oil insulation is employed, if the apparatus starts to break, the spark-gap will usually break simultaneously and will maintain the arc, while the oil closes the break in the apparatus and stops it almost instantaneously. Consequently, without very close inspection the original kick through the oil will pass unnoticed and the apparatus will appear to have withstood a potential as measured by the gap considerably higher than the actual impressed voltage under which it really broke down. On the other hand, when the spark-gap breaks first it introduces danger to the apparatus due to the sudden rise in voltage as pointed out in the paper. If testing apparatus of sufficient capacity is used, the ratio of transformation can safely be relied upon, especially since this may be checked up before the actual test, under different conditions by means of the spark-gap.

MR. M. H. GERRY. JR.:—Tests of apparatus for dielectric strength, as well as for any other purpose, should be made under conditions approximating at least those of actual service. It is useless, and may be positively harmful, to make strength tests under conditions differing widely from those under which the apparatus will actually operate.

There can be no objection to testing under any conditions, samples of insulation which fairly represent the material as a whole, used in the construction. If anything, there should be more of such tests, and less testing under severe strains of the finished product. We do not think of testing a steel structure as a whole up to the elastic limit of the material, but rather we confine such tests to samples representing the whole, and after determining the characteristics, we ascertain from the dimensions of the various parts of the structure, whether it is safe as a whole, and conforms to the requirements.

It may be urged that we possess a lesser knowledge of the strength of insulating materials than of the physical qualities of materials of engineering construction. I doubt if this be a fact at the present day. Insulating materials possessing a very fair uniformity of strength may be obtained; samples having been tested to determine the dielectric strength, and the heating under continuously applied strain, etc., it is possible, allowing a proper factor of safety, to predetermine the amount of insulation required, with practically the same accuracy as the strength of the materials in most engineering structures. It then becomes a matter of inspection to see that the required amounts of insulation are applied in the course of construction.

Reasonable insulation tests of finished apparatus, under conditions approximating those of service, are of course of some value in detecting serious errors in construction, but they are by no means conclusive evidence that the apparatus meets all requirements.

Mr. Thomas' remarks in reference to the effect of temperature on insulating material are worthy of most careful consideration. In this connection it should be pointed out that insulation may deteriorate after leaving the factory, due either to continued heating at operating temperatures, to chemical change, to the absorption of moisture, or to other causes. Insulation designed to withstand very high dielectric strain, especially if intended to operate under oil, should be carefully handled and protected in shipment. As mentioned by Mr. Thomas, large masses of material such as transformer cores, have a temperature lag, which tends to condense moisture under some conditions. This is a matter of importance especially in connection with the shipment of large high-tension transformers.

Mr. Peck:—I believe that apparatus should be tested under conditions which approximate as nearly as possible the actual operating conditions. Mr. Thomas advises the protection of apparatus under test by means of choke-coils or resistances inserted in the high-tension leads or in series with the spark gap where it is used for measuring voltage. These precautions are taken to prevent an abnormal concentration of voltage upon a few turns or layers of the winding when a sudden ground occurs or a spark-gap breaks down. If the apparatus while in service is to be protected by choke-coils or static interrupters, then it should be similarly protected during test; but if the apparatus is not to be so protected in service, it may be questioned whether it is legitimate to apply such protection during the test.

Mr. Thomas also advises a high test on apparatus before it is shipped, and a lower test after it is installed. The reason for this is that the insulation just after the apparatus is installed is in a weak condition due to the absorption of moisture during transit, and is not therefore in a condition to withstand severe tests.

The objection to this is that while the insulation is in bad condition, an excessive strain may occur and damage the apparatus. In fact, just after a plant has been installed when everything is new, and the men not accustomed to the methods of handling the apparatus, and the line has not been thoroughly tested, excessive strains are particularly liable to occur.

For these reasons it is my opinion that whether the apparatus is to be tested after installation or not, every precaution should be taken to put it into the best possible condition before it is placed in service.

Mr. Stott:—In regard to the testing of electrical apparatus, I think that the tendency of this paper is to discourage such things. Now, on what are we to depend for our factor of safety without an over-potential test. In all structural material for mechanical purposes we insist upon strength and we also insist upon a factor of safety ranging all the way from three to ten. Now, if we simply accept apparatus to run on normal voltage, we have absolutely no factor of safety protection. There may be one there, but we do not know it. There may be weak points developed and it is very much easier to take care of a breakdown of insulation on a test than it is in actual operation when you have a great many thousand kilowatts ready to burn it up. I think the tendency to discourage tests is distinctly against the best interests of the operating companies at all events, and therefore against the best interests of the manufacturer. Of course, there is a limit of safety beyond which a test should not be pressed, and that is a difficult point to decide, just what is that limit. I would say it should be 50 per cent. over-potential, 100 per cent. or 300 per cent.—the conditions will probably dictate just what that over-potential should be.

Reference has been made to moisture on insulation. I presume that refers more particularly to armature insulation. I have been working on some experiments recently on that subject, as far as surface leakage goes, and the experiment was carried on something after this style: A creeping surface amounting to about 4½ inches of insulation was established and the test used in an atmosphere of steam—simple atmospheric pressure saturated steam—and that steam had apparently no influence whatever upon the surface leakage. The only thing that had any influence was the presence of dirt of any description. So long as the insulation was absolutely clean, we went up from 40,000 volts on a 4½ inch surface, and had no effect whatever. So that I think that that statement as to moisture should be qualified a little. The moment dirt of any description was introduced on the surface, such as particles of oil or carbon dust, or particles of dust and oil floating in the air, then the insulation broke down immediately in the presence of moisture.

MR. LINCOLN:—Mr. Stott makes the analogy between the testing of mechanical apparatus and the testing of electrical apparatus, which I think hardly holds. When you test apparatus for physical properties—iron, for instance—take a test piece out of each cast or from whatever it is desired to test, put it into the testing machine and break it. If that method were followed in testing electrical apparatus it would meet the approval of the manufacturers; to take a sample of the insulation, put it into the machine and test its insulating qualities. But when Mr. Stott buys a dynamo he doesn't strain the bed plate until he breaks it. That is somewhat analogous to the over-voltage strain on the insulation of a dynamo.

MR. STOTT:—I did not mean to apply a strain to break down insulation, but a testing strain that would guarantee that there was a factor of safety in that material.

MR. LINCOLN:—The tested part would determine that, it seems to me.

MR. STOTT:—It would not determine the workmanship, however.

MR. GANO S. DUNN:—In the latter case the test of insulation on the armature is as much to determine whether the proper thickness of insulation is present as to determine whether that insulation, being present, is of the proper strength. (Quality of insulation can be supervised but quantity at every point not so easily.) Therefore, I side with Mr. Stott in feeling that a certain degree of high potential test is necessary.

MR. THOMAS:—Gentlemen, if you will read the last paragraph of my paper you will find that I do not recommend abolishing high-tension tests. I distinctly recommend them, only that they be made reasonable.

MR. W. L. WATERS:—When the insulation is designed for any high-tension winding, the engineer who designs it knows, or should know, at what voltage that insulation will break down.

assuming that it is tried and that it is in perfect condition mechanically. What he wishes to test for afterwards is to find out whether the insulation was damaged during manufacture or during transit.

The usual experience in the testing room is that if the insulation of a machine is going to break down on the high voltage test, it will do so during the first few seconds during which the high potential is applied. The reason for this is that if the insulation is damaged at all, it is usually totally ruined in certain places, so that it breaks down almost as soon as the high potential is applied. So I think that a more satisfactory test than the one-minute double-voltage test usually given would be a considerably higher voltage for a much shorter period. Take, for instance, a 20,000 volt transformer; the insulation of this transformer, if in perfect condition, would probably stand 80,000 volts for several minutes. The testing room high potential test I would suggest in such a transformer would be 50,000 volts for ten seconds.

When the machine is installed and is just going to be put into operation, it is to be tested again to see if it has got damaged during transit. Then I think a much lower voltage test, say a high potential test at 50 per cent., above the operating voltage and an insulation test, would usually be conclusive as to whether or not the insulation was in satisfactory condition.

MR. C. E. SKINNER:—In regard to the duration of test for the determination of whether the contract is fulfiled or not, I think the recommendation of the Standardization Committee is quite fair both to the manufacturer and to the customer. Their recommendation is for a test of double the potential at which the apparatus is to be used, applied for one minute. Longer tests are liable to cause trouble, as stated by Mr. Thomas, and the manufacturer usually makes his own tests higher to determine whether or not he has succeeded in carrying out his designs to his own satisfaction.

Mr. Thomas has perhaps given the impression that a great deal of caution is necessary. Caution is necessary, particularly with very high potential tests, but I feel that such tests should be carried out on all apparatus.

In regard to the method of application of the voltage, I think this might properly come up under Mr. Thomas' paper and very little is said about this matter.

There are three principal methods which are in use: The static voltmeter in the high-tension circuit; the direct reading voltmeter used with a multiplier; and the ratio of transformation measuring the voltage on the low-tension side. The spark-gap is recommended by the INSTITUTE, but I agree with a former speaker that it is an unsatisfactory and dangerous method.

Theoretically the static voltmeter in the high-tension circuit is the best, but it is difficult to obtain an entirely satisfactory static voltmeter. The use of a multiplier in connection with a direct reading voltmeter is open to the objection of large consumption of power on very high voltages and the difficulty of building and maintaining the necessary series resistance.

With large testing transformers the ratio of conversion is in most cases adequate for the purpose. There may be a slight rise of potential when the static capacity is considerable, but this is not of very great consequence. The amount is not sufficient usually to cause any particular damage, as the apparatus must have a strength considerably above the contract test in order to pass either without giving trouble.

In regard to applying the voltage, it is sufficient on low-tension apparatus, say, tests up to six, eight or ten thousand volts, to simply switch in the potential at which the test is made. There will be a rise of the e.m.f. across the testing terminals, but the factor of safety, if you may call it such, will be sufficient, or should be sufficient to stand this rise; and where hundreds and even thousands of tests are made every day, as they are in the large factories, it becomes quite a serious loss of time, in making the tests, if considerable time is taken to bring up the voltage. For the higher potentials, it is necessary to raise the potential gradually, and there are various schemes for doing this. One of the best is to have control of the generator. That is not always possible. Where we are obliged to make the test from a constant potential system, then it is necessary to introduce something in the nature of water resistance or of a step-by-step method, using very small steps. Where the capacity of the apparatus to be tested is quite small, such as insulators or small sets of cable, steps as large as 5 per cent. do not seem to be objectionable. Where the static capacity of the apparatus under test is large the steps must be smaller to prevent surges in the testing circuit.

MR. MERSHON:—I thoroughly agree with what Mr. Peck and Mr. Skinner have said. I have no love for what might be termed an " egg-shell " transformer. It seems to me that we want something that is going to stand a little rough knocking about. If we have to handle 40,000 and 50,000 volt transformers so gently, what is going to happen when we get up to the voltages that are being talked about 100,000, perhaps?

As regards the question of injury to the apparatus under test, at, for instance, double potential test for a minute. The problem is simply this, that we want to get apparatus which will meet and withstand the conditions of practical operation. Now we cannot state accurately and explicitly what those conditions are. Therefore, we cannot formulate explicitly any tests which will show whether or not the apparatus will meet them. The best we can do is to adopt tests which, in the light of experience, will probably come somewhere near telling us whether the apparatus is going to meet the practical conditions. It seems to me that a double potential for one minute is not any too high, and I can' tell you that it is very comfortable to know, under some conditions that obtain on transmission lines, that your transformers have stood such a test.

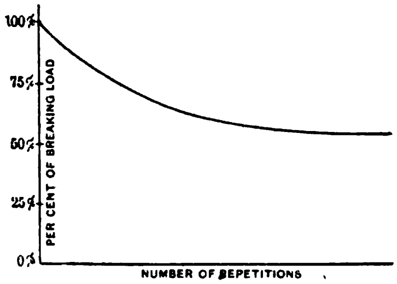
In regard to when and where the test shall be made, I want to emphasize what Mr. Peck says. It seems to me that the test should be made after the installation of the apparatus. We want apparatus that is going to stand the conditions to which it is subjected after it is installed.

The stand taken by Mr. Peck regarding the improvement in the condition of the apparatus after installation, I agree with entirely. Presumably the manufacturer gets his apparatus in the best possible condition before it is tested. It is not fair that the severity of the test should be reduced in any way because the condition of the apparatus is going to improve with time, when in the meantime the apparatus may be damaged by lightning or other disturbances on the line, and the burden of that loss fall upon the purchaser.

MR. DUNN:—What we need to solve a good many of these questions is data on the relation between the elastic limit of insulating materials and their ultimate break-down point, just as we have that data for mechanical properties of various materials. To refer to the case mentioned by Mr. Lincoln, I think it would be good engineering for Mr. Stott to try to break the suspected base of the generator with a reasonable excess of strain over what it was expected to stand regularly.

Insulation testing is of two kinds. One, as I said before, to determine whether the insulation is present. This is necessary even if a manufacturer is honest, because in putting conductors into slots and wires around cores, considerable mechanical pressure and hammering has to be used, which is liable to break the insulation or subject it to such pressure that its properties are injured. The other kind of testing is to determine whether insulation which we believe present is good. In this test we apply a stress that is above the elastic limit. If we could determine that the elastic limit of the insulation was say one-third of the ultimate limit, it would be proper for us to use a high potential test within the former limit. The stresses we put on apparatus in factory tests now are above that limit, and we keep them on but a short time in order not to damage the insulation too much. Such tests, I think, are bad. If one of the results of this discussion were the collection of data on elastic limits, it would be of great benefit.

PROFESSOR LANGSDORF:—There is another kind of test, which so far as I know has never been applied to insulating material. It is analogous to those which are made upon metal, and recently upon cement, to determine the effect of fatigue. I have recently seen a curve which was made from the results of tests of this nature on cement that looks something like this (indicating); the number of repetitions necessary to produce failure are plotted as abscissæ, and percentages of the normal breaking load as ordinates. The curve is apparently logarithmic and approaches an asymptote passing approximately through the 50 per cent. division on the scale of ordinates; this would mean that the factor of safety as ordinarily understood is only half the assumed value; so that if tests of this nature could



be made on insulators we might get a little more light upon the value of the factor of safety.

Mr. Henry Pikler:—When we are testing electrical apparatus we assume a sine wave e.m.f. This is true as long as the step-up transformer is directly connected to the terminals of the generator which furnishes the sine wave high voltage, but as soon as we use resistances in series with the transformer in order to control its terminal voltage the wave-shape of the e.m.f. changes. You know very well that the hysteresis, or more correctly, the change in the permeability during one cycle of magnetism distorts the wave-shape of the magnetizing current; but if we have it in the circuit besides the transformer, a series ohmic resistance, then this will cause the distorted current to change again to a sine wave. And when a sine wave current excites the transformer, its induced e.m.f. will be no longer a sine wave but a highly peaked wave, and we subject the tested apparatus to a voltage which is perhaps 20 per cent. higher than we are calculating on. I made some experiments in this regard, and I found that the more the energy consumed by the ohmic resistance comparatively to the energy consumed by hysteresis in the transformer, the less will be the distortion of the current wave, it will become more and more sinusoidal. But if the transformers get a sinusoidal magnetizing current, its induced e.m.f. wave will be distorted; assuming as a limit a perfect sine wave shaped exciting current. The induced e.m.f. wave of the transformer will have exactly the same shape as the exciting current curve has, when the current drawn from the sine wave generator is only that due to the transformer, the secondary of which is open.

It has been suggested that we should know the relations between the ultimate strength and the elastic limit in insulating materials. The insulation engineer has a very difficult problem to handle. With low voltages it is fairly simple; but when we get up to the higher voltages, there arises a new order of affairs. One of the things to guard against particularly is that we do not encounter unawares a new kind of phenomenon. For example, when we test at two or three times normal voltage, we are simply endeavoring to determine the breaking down strength. Some new phenomenon like dielectric hysteresis may come in to produce heating, or in suddenly applying the voltage for test there may be some sudden rise of voltage which was not anticipated. It is things of this kind, these incidental and unexpected things, which we must guard against particularly.

MR. THOMAS:—I will take only a moment or two. The building and testing of high-tension apparatus, transformers or generators, is an extremely intricate and complicated problem, and no person who has not worked on a design and used such material can have any real appreciation of the difficulties involved. These criticisms and recommendations, if we may call them such, which I have drawn up here, are based on a very long line of experience, tests, actual apparatus troubles, and represent a very careful consideration of all the data.

Mr. Peck began by calling attention to the fact that the apparatus is likely to get strains on layers near the terminals of the transformers during the early testing of the line and that tests ought to be made in apparatus purposely to apply these strains. This would certainly be very desirable on the face of it, and is desirable if it can be carried out practically. But this great difficulty is met; Suppose you make the test and our transformer fails to stand it. You can't always know the fact. A spark occurs between two layers inside somewhere, and since the apparatus is, in all probability, not in a position to be supplied with generator current to the full capacity of the system, your insulation is punctured, the spark passes and ceases, stops, and you think the transformer is all right. You go ahead and a little later a strain of much less magnitude comes along and when conditions are favorable for that fault to be developed, and the general apparatus breaks down. That is one of the difficulties.

[CONTRIBUTED AFTER ADJOURNMENT BY DR. LOUIS BELL.]

I do not think it wise for a purchaser of apparatus to place much reliance on over-voltage tests set forth in contracts, save in the case of line insulators, switching and such-like simple apparatus. In other cases such tests ought not to be long continued, and should not be made until the apparatus has successfully stood a full load test and recovered therefrom. Then a moderately severe over-voltage test can be usefully applied, merely to try out the insulation as a whole. I do not concur that a disrupture test is unfair because it may subject to severe strain parts of the insulation which normally receive in commercial working only a moderate strain. The disrupture test ought to try out these very points, for danger to insulation from minor lightning discharges, resonance and the like frequently catches apparatus at just these weak points, since trouble usually comes from abnormal, not ordinary, conditions. Personally, I attach some value to an overload test at a voltage somewhat greater than will ever be demanded in practice, with careful insulation measurements before and after.

[CONTRIBUTED AFTER ADJOURNMENT BY MR. P. G. GOSSLER.]

The grounded wire method of protection against lightning has been used on the transmission lines of the Montreal Light, Heat & Power Company for the last four years, with very satisfactory results. For three years the transmission lines were operated at two-phase, 12,000 volts and for the last year at 3-phase, 25,000 volts.

The 2-phase transmission lines consisted of duplicate lines run from Chambly to Montreal, the total distance being about 17 miles for each line of which 14½ miles were ærial and 2½ miles single-conductor rubber-insulated underground cables. The underground-cable was divided up in three sections, the first section was about a mile and a half from power house, the second about 15 miles from the power house, and the third at the Montreal end.

The present transmission lines consist of duplicate lines, 17 miles for each line of which 15½ miles is ærial, and 1½ miles underground cables at one end. Three lines of barb wire are run on pony glass insulators on each pole line, two lines being run on the ends of the top cross-arms 32 inches from the line wire, and the third on a pin on the top of pole.

The barb wire is composed of two twisted No. 12 B.W.G. galvanized iron wires with one four point barb every five inches, and is connected at each pole by means of a soldered joint to the ground wire. This ground wire is stapled down the face of the pole and is twisted several times round the butt, after running through an iron pipe about 8 feet long, which projects above the level of the ground, preventing the wire from being cut or broken, as well as affording an additional ground.

As the poles are set 90 feet apart the barb wire lines are grounded about fifty-eight times per mile; this frequent grounding being one of the most important points in the protection.

It has been the general opinion that ordinary barb wire lacks good mechanical properties, is liable to corrosion and to cause interruption to the service by breaking and becoming tangled with the transmission wires.

This has not been our experience. In the line described above, ordinary commercial barb wire was used and we have only experienced two cases of the barb wire breaking. In both cases it fell clear of transmission wires and did not become entangled with the conductors. We are of the opinion that our freedom from mechanical troubles has been due to the care exercised when stringing the line, and also fastening to a glass insulator, instead of stapling to the cross-arms and top of poles.

We also use the Westinghouse low equivalent a.c. lightning arresters, in conjunction with the barb wire. Banks of arresters being located at both ends of the ærial lines.

We have undoubted proof of the usefulness of barb wire protection as applied to our system. The first year and a half of operating our 12,000 volt Chambly Plant we did not have any protection against lightning but the barb wire. The first summer we had the opportunity of watching the effect of a very severe storm which traveled from Montreal to Chambly, passing over the district through which our transmission lines run; this storm did considerable damage in Montreal, shattered several trees along the transmission line, and also damaged the local lines in Chambly, but no trouble was experienced on the transmission lines.

So satisfied are we of the usefulness of barb wire as a protection that we have installed it on many of our local 2400-volts circuits in and around Montreal, with satisfactory results.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, July 1st, 1903.

CHOICE OF FREQUENCY FOR VERY LONG LINES.

BY P. M. LINCOLN.

Although other frequencies are in use in this country, there are only two which by the extent of their use can be called standard, viz.: 60 and 25 cycles per second. Without discussing the relative merits of other frequencies, the question now presented is, which is the better frequency for a very long line, 60 or 25 cycles per second, considered purely as a transmission problem.

In the present state of the art, 200 miles may be considered as very long for a transmission line. Although longer ones have been proposed, only one of this length has been put into actual operation and no other line approaches this length. The reasoning which follows will, therefore, be made to apply to a typical line 200 miles long.

Frequency has a direct bearing upon voltage regulation and charging current and its influence on a possible condition of resonance may also be profitably discussed.

1st. *Voltage Regulation.*—The difference between the voltage at the transmitting and the receiving stations, termed the " drop," is dependent upon several elements, among which are the resistance and the inductance of the circuit. The volts for overcoming the resistance are the same as would be required for sending a direct current equal to the normal alternating current through the line, if it be short-circuited at the receiving end. The volts for overcoming the inductance at any frequency are measured by the pressure which would be required for sending the alternating current at that frequency through the short circuited line, if the ohmic resistance were negligible. The inductance volts are directly proportional to the frequency. The difference in voltage between the transmitting and receiving stations, or the " drop," is a function of the resistance volts, the inductance volts and the power factor of the load.

Consideration of voltage regulation at the receiving end limits, according to best practice, the resistance volts in a transmission line to about 15 per cent. as a maximum, and the same consideration should keep the inductance volts within a maximum of 20 per cent. This will mean a line regulation of about 24 per cent. with a load power factor of 85 per cent. Best economy may reduce the resistance element below the maximum given. The resistance volts may be reduced to any given amount by the addition of copper, while inductance volts are little affected by increasing the size of wire. An increase in size of conductor which will reduce resistance volts by one-half will reduce inductance volts only about 5 per cent. The matter of inductance volts, therefore, constitutes a limit to the amount of power that can be delivered over a single line. This consideration will limit the amounts of power which can be delivered by a three-phase line 200 miles long to approximately the following:

TABLE SHOWING LIMITS OF TRANSMISSION LINE CAPACITIES.

Voltage at Receiving End. 200 Mile, 3-Phase Line.	Power Delivered with 20% Inductance Volts.	
	60 Cycles.	25 Cycles.
20,000 Volts	500 k.w.	1,250 k.w.
30,000 "	1,125 "	2,800 "
40,000 "	2,000 "	5,000 "
50,000 "	3,125 "	7,800 "
60,000 "	4,500 "	11,250 "
80,000 "	8,000 "	20,000 "

For longer or shorter lines the k.w. in the above table may be decreased or increased in direct proportion.

If the amount of power to be transmitted is large, the multiplication of lines necessary at 60 cycles unduly increases expense both of pole lines and of right of way for same. This point is evidently in favor of the lower frequency.

2d. *Charging Current.*—Charging current is, of course, a direct function of frequency and voltage and to a slight extent of line construction. At 60 cycles the apparent energy represented by the charging current in a 200-mile three-phase line is practically equal to the ultimate capacity of that line as limited by the 20 per cent. inductance volts consideration. At 25 cycles it is only about 15 per cent. of the ultimate capacity as limited by the same consideration. In a 60-cycle installation, therefore, it is necessary either to operate the generators on such a line at about full current output all the time, no matter what the load, or to compensate for the charging current in part or in whole by the installation of choke coils, either horn of which dilemma is not pleasant to consider. The problem of taking care of the charging current at 25 cycles does not enter the discussion as compared with 60 cycles.

The effect of a large charging current on the regulation of the generator should also be considered. As is well known, a line charging current, when circulating in a generator armature, has the effect of assisting the field ampere turns to magnetize the fields. The percentage of magnetizing done by this charging current depends upon its amount and the inherent regulation of the generator. Since the charging current depends upon the voltage, the generator exciting power of the charging current also depends upon the voltage. The effect of sudden load changes, therefore, which tend to change the voltage delivered, will in turn affect this element of the excitation. That is, to a certain extent, the generator assumes the regulation which inherently belongs to a d.c. shunt generator. The effect of large charging currents on generator regulation is, therefore, not toward an improvement.

3d. *Resonance.*—As is well known, every combination of a condenser and choke coil in series has a natural period of oscillation, whose value depends upon the square root of the product of the condenser capacity by the choke coil inductance. If a frequency of its natural period be applied to such a combination, resonance will occur. That is, a small exciting force of the proper frequency will cause comparatively large currents to circulate between the condenser and the choke coil and therefore comparatively large voltages across both the condenser and choke coil. This is an example of resonance in its simplest form.

A transmission line possesses both capacity and inductance, and therefore the possibility of becoming resonant under certain conditions. The fact that both the capacity and inductance of a transmission line are distributed throughout its entire length, and the disturbing effect of concentrated inductances and capacities at transmitting and receiving stations, makes the problem of determining under what conditions resonance will occur an extremely intricate one. A first approximation may be obtained, however, by assuming that the inductance and capacity of a line are concentrated instead of distributed, and omitting the effects of translating devices. Under this assumption, we may consider that the capacity of a distant portion of the line is in series with the inductance of the intermediate portion.

The natural period, that is, the applied frequency at which resonance will occur between the parts of a transmission line, will be a minimum when the two parts are equal, or each is equal to one-half the total line. The number of natural periods above this minimum is infinite, since it is possible to divide the line into two parts, the inductance of one of which multiplied by the capacity of the other may be any quantity less than that obtained by dividing the line into two equal parts.

The minimum period of a 200-mile line is approximately 200 cycles per second. There is, of course, no danger that the fundamental applied frequency will produce resonance until the length of line largely exceeds 200 miles, but the same cannot be said of some of the harmonics if they are sufficiently prominent. The lower the fundamental frequency, the less is the danger from this source. So far as the writer is aware, no actual trouble has ever been experienced in existing plants from this source even on the longest lines and highest frequencies in use, but it nevertheless constitutes an advantage for 25 over 60 cycles that cannot be dismissed with a scoff.

It is a fact that the longest transmission line in the world—the Bay Counties line in California—as well as the highest voltage line—the Missouri River Power Company in Montana—are both operating at 60 cycles. These facts, however, do not detract from the force of the preceding reasoning.

It is not claimed that this discussion contains all of the arguments pro or con. The bringing out of additional points as well as the soundness of those presented, is left to the discussion which it is hoped the above will provoke.

WEDNESDAY—AFTERNOON SESSION.

President Scott called the meeting to order at 2.30 P. M.

MR. B. A. BEHREND:—Mr. Lincoln's figures indicate clearly that, with a given amount of material in a long line of power can be transmitted at 25 cycles than at 60 cycles. Mr. Lincoln calls attention to the possible danger of resonance as produced by the higher harmonics superimposed upon the fundamental used for the transmission. Mr. Lincoln says: "The fact that both the capacity and inductance of a transmission line are distributed throughout its entire length, and the disturbing effect of concentrated inductances and capacities at transmitting and receiving stations, makes the problem of determining under what conditions resonance will occur an extremely intricate one. A first approximation may be obtained, however, by assuming that the inductance and capacity of a line are concentrated instead of distributed and omitting the effects of translating devices."

I showed in a brief contribution to M. Leblanc's paper at the Convention of the INSTITUTE last year that the natural period of oscillation of a transmission line with distributed capacity and self-induction can, without difficulty, be calculated. The method in my contribution requires no extraordinary mathematical knowledge beyond simple differential equations, and I have shown on page 1213 of our volume XIX of 1902 that the fundamental of the natural frequency of oscillation of the line is:

$$\frac{1}{4_l \sqrt{L\,C}}$$

while the natural frequency, if we assume the capacity and self-induction to be concentrated, is equal to,

$$\frac{1}{2\,\pi\,\sqrt{L_1\,C_1}}$$

The discharge frequency of a long line with distributed capacity and self-induction is, therefore, greater than if the capacity and self-induction were concentrated.

Although this is all very interesting, I feel somewhat skeptical about the practical importance of this resonance. It may be possible that such resonance occurs on long transmission lines, but I should prefer to suspend judgment on this point until the facts had forced themselves upon my attention. I cannot help thinking of the unreasonable importance which at one time used to be attributed to the wave-form of alternating current generators a case which has almost entirely broken down. But, at one time, the wave-form was the scapegoat for all sorts of mistakes made and a perfect bugbear to the designing engineers.

In considering the question whether a frequency of 25 or 60 cycles is preferable for power transmission purposes, we should not confine our attention to the line itself, but we should take into consideration the generating plant, the transformers and the substation as well. In regard to the generating plant and the transformers, there can be no doubt that a frequency of 25 is rather lower than desirable. In regard to the substation apparatus, a frequency of 25 is as high as desirable for rotary converters, while it is too low for lighting. Is not, after all, then, Mr. Lincoln's problem the same that has been argued for fifteen years, viz., the problem of the most favorable frequency?

I may add to Mr. Lincoln's statement to the effect that the longest lines, as the Bay Counties and the Missouri River, are operated at 60 cycles, that the first long distance transmission line of 115 miles in length between Lauffen and Frankfort, which was built in 1891, was operated at a frequency of 50.

MR. F. G. BAUM:—The first criticism I have to make on this paper is that it confines the discussion of the choice of frequency to the transmission line.

Unquestionably, so far as the line is concerned, the lower the frequency the better the regulation, and the greater the capacity of the line, limiting the capacity of the line by the inductive volts. But the fallacy of reasoning that a low frequency is, therefore, to be used, becomes immediately evident if we pass to the transformers, where the higher the frequency, the smaller the weight and cost, and the greater the efficiency.

The best frequency for the generators is, of course, dependent upon the speed at which they are driven, and on their capacity. With slow speed engines, low cycles would no doubt be preferable, but in water power plants, operating at speeds from 300 to 500 r.p.m., with peripheral speeds of about 10,000 feet per minute, according to the head of water used, the best frequency for the generators will be higher than when driven by low speed engines.

A power company at the present time, in California at least, if it is to be a success, must sell a good proportion of its load to small towns for lighting, etc. These towns being already equipped with 60 cycle apparatus, practically force the power companies to supply that frequency.

As to the limits of the percentage of resistance pressure or copper loss, I believe 15 per cent. as a maximum is a little high, and a satisfactory system should probably not have over 10 or at most 12 per cent. The limit of 20 per cent. for the reactance pressure is, I think, a little low. As it is possible generally to have pretty fair control of the power-factor of the line, a maximum of 30 per cent. for the reactance pressure would, I think, not be excessive, and would give satisfactory service.

The charging current is not difficult to handle. If the load is to be mostly induction motors, the charging current will improve the power-factor of the generators. However, a 30 cycle system would be better than 60 cycle so far as handling the charging current is concerned.

Undoubtedly if our lines are to increase in length to 300 and up to 500 miles, we must operate at less than 60 cycles, in order to reduce the reactance volts and also on account of coming into resonance with the line.

President Scott:—This paper is another example of what was referred to this morning in another connection; namely, the new class and order of phenomena which may appear when the voltage is changed. The various points which have been taken up in this paper; namely, regulation, charging current and resonance, have little or nothing to do with the choice of frequency at low voltages. For instance, in an installation of an isolated plant, or one for short distances, in which the voltages are not more than a few thousand. But when the higher voltages and the longer distances come in, then these new problems appear; new elements have very great importance, sometimes they are even the limiting conditions. The subject is one which is open now for general discussion.

Mr. Mailloux:—It seems to me that in a matter of this kind the consulting engineer is confronted more by conditions than by theories. If he has to consider locations where the electrical energy is to be used principally for lighting, he must of necessity adopt a frequency that will be compatible with satisfactory lighting. In all the cases which I have had to deal with in long-distance transmission thus far, that condition has been imposed by the facts and circumstances of the case. It has been necessary to make provision for a current capable of giving satisfactory lighting, because the bulk of the current was intended to be used for that purpose. Now the question it seems to me, therefore, would be, in striving to obtain a compromise between extremes, to determine what is the minimum frequency that is satisfactory for lighting purposes. Experiments have been made with the various frequencies in Europe. There are many plants which are furnishing or attempting to furnish lighting current with frequencies as low as 40. I have seen several of those plants, and I must say that I do not consider them satisfactory. One can see stationary objects very well, but moving objects seem to have a jerky motion which is unpleasant and even annoying. I would like to know if any of the gentlemen present have had experience with frequencies as low as 50. It has occurred to me several times that perhaps a frequency of 50 might be a satisfactory compromise. We all know that 60 is perfectly satisfactory for lighting, but it would be very interesting to know what experience has been had with frequencies lower than 60, in this country.

Mr. Stott:—As to the frequency at which incandescent lighting becomes impossible, I think that point comes at just about 20 cycles, from some experiments which have been carried out. Twenty-five cycles, with a low efficiency lamp, taking about 4 watts per candle, and with a voltage not to exceed 110, where the filament is comparatively heavy, is quite satisfactory. We have tried the experiment of having direct current lighting in the draughting room and then without notice throwing it over on the alternating current, and no one knew anything about it; and this certainly demands the best light possible.

PRESIDENT SCOTT:—You are using it in the elevated stations in New York.

MR. STOTT:—Yes; we have about 30,000 incandescent lamps run now on 25 cycles, and very few people notice the fluctuation. I think it depends a good deal upon the voltage regulation and also upon the fact that low efficiency lamps are used.

MR. MAILLOUX:—How about the Nernst lamp?

MR. STOTT:—I have no information about the Nernst lamp. I understand 25 cycles is rather low for it. In reference to the general proposition of frequency, it seems to me that it is a local condition which must be considered in connection with every individual proposition, which is brought up.

MR. MERSHON:—Mr. Lincoln considers his subject purely as a transmission problem. It is not very often that you get a chance to consider the engineering of transmission from that standpoint. You generally have to take into account certain conditions that have to be met. You cannot select the frequency of your apparatus just as you choose. Now, in many of these cases—I guess it has been true of all the California plants—I think it is true of most all the transmission plants that have been put in—the condition to be met first was that of delivering power at 60 cycles. The transmission enterprises could not have existed, probably, if you had insisted on putting in the 25 cycles, in that there would not have been enough immediate prospective market to have made it possible to finance the enterprise, and in order to get this market, and get it as soon as the plant was in operation, it was necessary to deliver 60 cycles. In such a case, the question comes down to whether or not it is better to transmit at 25 cycles and use frequency changers for 60, or whether it is better to transmit at 60 cycles and use synchronous motors to raise the power-factor of your load, or even bring up the drop in your line to approximately that of the copper drop. If you consider the question of the investment in these cases, you will find that the 60 cycle plant shows up much more favorably. Take, for instance, the use of motor generators for changing your frequency from 25 to 60 cycles—you would require, with a power-factor of 85, which is the one Mr. Lincoln has taken, approximately 220 per cent. in actual machine capacity, counting both motor and generator, and the fact that your generator has got to be able to take care of a power-factor of 85. If you are using synchronous motors and bring your power-factor up to unity, it will require about 53 per cent. Now, that represents not only the cost of the machines, cost of the switchboard apparatus for handling them and cost of station room for installation of machines, but in addition to that there is the question that has been mentioned of the less cost of the transformers for 60 cycles. As regards the question of the charging current on 60 cycles, if synchronous motors were used, you would be able to get a greater amount of power over a single line than Mr. Lincoln has calculated. Besides, you could reduce the effect of the capacity current on the generator by means of these synchronous motors, by keeping some of them running at light loads just as you would have to do in case of frequency changes. I cannot see that the capacity current of the line will seriously affect the generator regulation. The generator excitation depends upon ampere-turns either in the field winding or the armature winding. To the over-excitation, required to neutralize the armature-reaction of a given lagging load, is due, mainly, the rise in voltage when such a load is thrown off. If the same lagging load be carried but in conjunction with a charging current, such as brings the power factor at the generator terminals to unity, the unity condition is due to the fact that the reaction component of the lagging load has been neutralized by the charging current. When, therefore, the lagging load is thrown off, there is left on the generator the charging current whose effect on the generator magnetization is about equal to, in fact somewhat less than, that of the over-excitation previously referred to. True, the rise of voltage tends to increase the charging current which in turn tends to increase somewhat the voltage rise, but this cumulative action will be held in check by the fact, just referred to, that ampere-turns in the armature are less effective in raising voltage than an equivalent number of ampere-turns in the field.

As regards the question of frequency in lighting, I think there is an element to be considered that has not been mentioned, namely, personal peculiarities. I have tried in a number of cases to find out the impression made on different people by low frequency lighting. At 25 cylces, if I endeavor to do so, I can notice a flicker in any 25 cycle installation I have ever seen, but it does not bother me. Some people say that it annoys them at all times, and some people say that they can even see the flicker in the case of frequencies considerably above 25 cycles. I think, however, that the majority of people cannot notice any effect from 30 cycles. Possibly they could with quick movements of illuminated objects, but I do not think that with the ordinary movements of every day life they would notice any flicker at 30 cycles.

Mr. Rushmore:—An interesting instance came to my notice some time ago in talking with an engineer of one of the large transmission systems. On some of their new lines, he said that they were using a maximum distance between wires for the purpose of obtaining the greatest possible line inductance, the rise in voltage being greater than was desirable.

The form of e.m.f. curve has been mentioned as being something about which we need at present concern ourselves but little. This is quite opposed to my own view. The capacity charging currents on these high voltage lines very considerably amplify any harmonics which may exist in the original wave.

Under such conditions, it is necessary that the wave form approximate closely that of a sine function. In modern generators this is the case, which perhaps explains to some extent the reason why but little is heard on the subject.

MR. LINCOLN:—Mr. Mershon advanced the idea that synchronous apparatus could be operated at the receiving end of the line to compensate for the inductive drop. I wish to take issue on that point. It is possible so to operate synchronous apparatus that the current at the receiving end of a transmission is either lagging or leading with respect to the e.m.f. at the will of the operator. That is, the inductive "drop" in the transmission may be made to subtract from or add to the generator volts at the will of the operator. This fact, however, is not going to help line regulation, that is the change in receiving end voltage for a given load change—unless the field strength of the synchronous apparatus can be changed automatically with load. The limiting factor in very long lines is regulation and I do not see how Mr. Mershon's scheme of putting synchronous apparatus at the end of the line helps regulation. And for the same reason I would differ from Mr. Baum where he places the real loss in a transmission line at somewhat less than I have. I have placed it at 15 per cent. He says it is not over 10 per cent. or 12 per cent., and he places the inductance drop at 30 per cent., instead of 20 per cent., as I had it. That inductance drop is going to have an important influence in the regulation of the line, and if we are going to limit our regulation to 25 per cent., I don't see how you are going to allow 30 per cent, inductance drop, particularly with loads of low power-factor.

MR. MERSHON:—I cannot quite agree with Mr. Lincoln. The action of a synchronous motor with a constant excitation is similar to that of a condenser so long as the voltage impressed upon the motor does not vary, but as soon as the voltage begins to vary the similarity ceases. If the voltage rises on a condenser the condenser takes more current. If the voltage rises on an over-excited synchronous motor the motor takes less current. The voltage may rise to a point where the motor will take practically no current or it may increase to a point enough greater than this so that the motor instead of taking from the line a leading current, it will take a lagging current tending to pull down the voltage, or rather, limit the rise. The action of the idle synchronous motor is therefore corrective which a condenser would not be. This corrective action of a synchronous motor will depend for its amount on the inherent regulation of the motor. If we chose to go to extremes we might make the synchronous motors dominate the system completely as regards the delivered voltage and might keep the voltage variation as low as we pleased by employing motors with very low inherent regulation.

DR. PERRINE:—I would like to say that whether it is possible or not to regulate a line with a synchronous motor as the last speaker describes, it has never been done; but the regulation of the line by means of an automatically excited synchronous motor has been done and was described by Mr. Baum in his paper presented before the meeting last year, where he showed how he regulated by means of an automatic exciter the voltage of the Bay Counties line at Oakland, overcoming the effect of capacity and inductance on the line by means of synchronous motors.

Mr. H. A. Storrs:—If the discussion need not be limited to 200 mile lines, there are one or two points which might be of interest. First, as regards the highest frequency which will produce a noticeable flicker in the lamp. A number of years ago in the laboratory at Columbia College we had a small rotary converter which was under control so that we could produce alternating currents of any frequency we desired, and we made a good many tests with 15 or 20 students at a time, in order to determine what frequency could be detected. The condition is quite different from what it is to go where a system is being operated at 25. You know the frequency, and you look at a lamp, and you say, yes; you can see the flicker of the light. But if you start with a high frequency and gradually lower it, telling everybody to keep his eye on the lamp, different men will at different instants say that they detect a flicker; and if, as you repeat that experiment, the same man detects a flicker repeatedly at the same frequency, why that is pretty good proof that he does detect the flicker. Under other conditions there is a good deal of imagination about whether you detect the flicker or not. As a result of a good many experiments of that kind, with lamps of various efficiencies, we found that 20 or 21 was about as high a frequency as any man could detect repeatedly. In fact, the majority could not detect a frequency of 20.

President Scott:—I would like to call attention to one thing. We are here dealing with certain engineering problems. We have a paper here which deals with the engineering question. What are the factors in connection with a line, a very long line, which bear on the determination of frequency; and we have gotten off from that into a whole lot of commercial things which have nothing to do with this question. What have incandescent and arc lamps to do with this? Mr. Lincoln has shown us here that certain facts prevail if we want to transmit at 50,000 volts, 200 miles. If we get beyond 3,000 kilowatts, we are going to exceed certain engineering limits which he has assigned, and he has done well to call our attention to those things, and bring them in as an engineering problem. The specific application will come in somewhere else.

Mr. Mershon:—Mr. President, will you allow me to take issue with you in six words.

President Scott:—In a moment. I call attention to this at this time, so that in this discussion we may endeavor to keep in on the plane of engineering rather than commercialism; not that the commercial is not important, but that the other is the important thing here. Now, in six words, Mr. Mershon.

MR. MERSHON:--It seems to me that if you confined this question of frequency to the transmission line alone, there would not be any discussion. We would agree on the 25 cycles or perhaps on direct current. It seems to me that an engineering problem is always more or less commercial. A physical problem is not an engineering problem until it is commercial; it is simply scientific.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 1st, 1903.

Y OR △ CONNECTION OF TRANSFORMERS.

BY F. O. BLACKWELL.

The two alternative methods, Y or △, of connecting transformers to a three-phase system, come up for discussion with every three-phase installation. A general statement of the advantages and disadvantages of both connections, as they appear to the writer, is given here with the hope that those engineers who have had most experience with power transmission will contribute their views on the subject.

TRANSFORMERS.

Assuming that three transformers are to be used for a three-phase power transmission, and that the potential of the line is settled, each of the transformers, if connected in Y, must be wound for $\frac{1}{\sqrt{3}}$ or about 58 per cent. of the line potential, and for the full line current. If connected in △, each transformer must be wound for the line potential and for 58 per cent. of the line current. The number of turns in the transformer winding for Y connection is, therefore, but 58 per cent. of that required for △ connection and the cross section of the conductors must be correspondingly greater. The greater number of turns in the winding, together with the insulation between turns necessitates a larger and more expensive coil for △ connection. The larger coil calls for a longer magnetic circuit and consequently a larger and heavier transformer throughout. This is of no importance when the potential of the coil is low or when the transformer is large and the current high. In fact, in transformers in which the current is heavy it is usual to divide the conductors into several multiple circuits for ease of handling and to avoid eddy current losses that occur when the cross section of the conductor is too large. A few turns more or less in the winding under such conditions is, therefore, immaterial.

In transformers of small capacity wound for high potential, the cost and weight are both considerably in favor of the Y connection of the high potential coils.

Where it is desired to secure the smallest transformers that can be wound for any given potential, the minimum size of wire that can be employed in the windings of the high potential coils and give sufficient mechanical strength, is the limiting feature. A transformer practicable for Y connection may be smaller therefore than can be commercially considered for △ connection.

The Y connection requires the use of three transformers, and if anything goes wrong with one of them the whole bank is disabled. With the △ connection, one of the transformers can be cut out and the other two still deliver three-phase power up to their full capacity; that is, two-thirds of the entire bank.

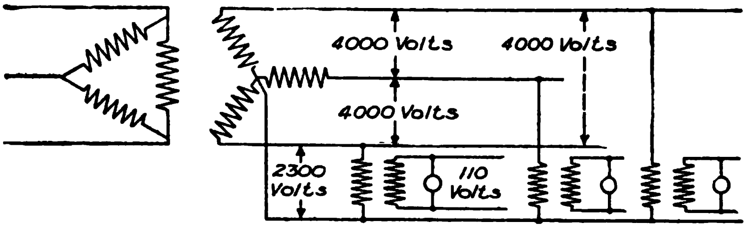


Fig. I Step Down Transformer For 4000 Volt Y Distribution

Combined three-phase transformers are generally of small size and on that account are preferably Y-connected on the high potential side.

GROUNDING THE NEUTRAL.

If the common connection of transformers joined in Y is grounded, the potential between windings and the core is limited to 58 per cent. of that of the line, and the insulation between the windings and core might be proportionally reduced. The same argument applies to the transmission circuit and would allow the size of the line insulators to be reduced.

The saving that can be made in insulating transformers by grounding the neutral is not great with large transformers, but is important on small ones, as the space taken up by the insulation for any given potential is relatively greater in a small transformer. Under normal conditions, the potential between any conductor of a three-phase transmission circuit and the ground is 58 per cent. of the line potential, with either Y or △ connection, but the neutral may drift so as to increase the potential with an ungrounded system. If one branch is partly or completely grounded, the potential between the other two branches and the ground is, of course, increased and may be the full line potential. With a grounded neutral Y system, a ground is a short circuit of the transformers on the grounded branch and the transmission becomes inoperative.

From the point of view of safety to life and prevention of fires this is a desirable condition, especially if the low tension distribution is also grounded. If the high tension circuit makes contact with the ground or low potential system, it can be immediately cut out by fuses or automatic circuit breakers.

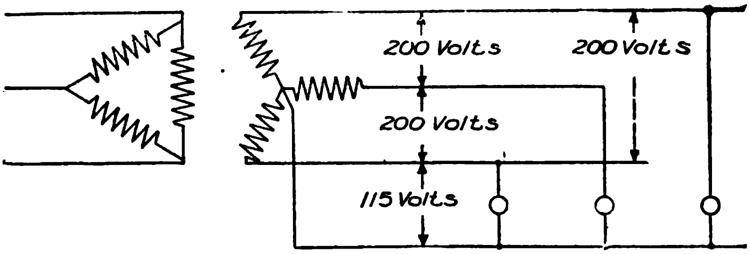


Fig. 2 Step Down Transformer For 200 Volt Y Distribution

The difficulty is that a power transmission with grounded neutral is likely to be frequently shut down by temporary grounds, such as would be caused by a tree blowing against one of the wires. Even if the circuit is not opened, the drop in the pressure due to the sudden " short " on the line will cause synchronous apparatus to fall out of step. Under the same conditions a system without a grounded neutral would give uninterrupted service.

UNSTABLE NEUTRAL.

If two transformers are connected in series, there is no certainty that they will divide the potential equally between them. A system in which all the electrical apparatus is connected in Y has somewhat the same characteristics. The neutral may drift out of its proper place and there will be unequal potentials between it and the three conductors of the circuit, due to unequal loading and differences in the transformers or transmission circuits. Such unbalancing would cause unequal heating of the transformers and if a four-wire three-phase system of distribution were employed, would seriously interfere with the regulation of the voltage. In transformers, therefore, have Y secondaries, it is desirable that the primary should be △ connected. Two systems in common use with which △ primary windings should be used, are shown in Figs. 1 and 2.

RISE OF POTENTIAL.

The high potential windings of transformers are necessarily of high reactance, and if left in series with a circuit of large capacity, as shown in Figs. 3, 4, 5 and 6, the leading charging current flowing over the reactance may set up extraordinarily high pressures. Figs. 3 and 4 represent Y connected banks of three transformers, each connected so as to cause such a rise of potential. In Fig. 3 the primary of one trasformer is excited by a generator, the primary of the other two transformers being open-circuited. In Fig, 4 the primary of one transformer is open circuited, the other two being connected to the generator. Figs. 5 and 6 show T connected banks of two transformers, which might be used to transform from either two-phase or three-phase to three-phase or vice versa, and are similar in action to Fig. 3. If in any one of Figs. 3, 4, 5 or 6 the secondaries are connected to a long distance transmission circuit, a pressure of many times the normal potential will be set up between A and B, and between B and C, that between A and C not being affected.

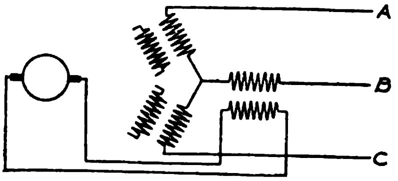


Fig. 3

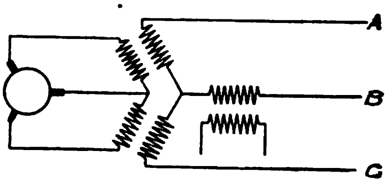


Fig. 4

It is theoretically possible for a potential 100 times that for which a transformer is wound, to be caused by opening the primary switches of one or more of the transformers of a bank connected in Y before the secondary switches are used. Of course, actually, the current jumps across the insulation at some point in the system before there can be any such increase in pressure. If there are a number of banks of transformers in parallel, this phenomena cannot occur except when all but one bank are disconnected. This source of trouble could be obviated by employing oil switches on the high potential side which disconnect the line before the low tension switches are used, or by triple pole switches on the primary which open all three branches of the bank of transformers at once.

The selection of Y or △ connection of transformers for long distance transmissions should only be determined after a careful consideration of the conditions in each case.

There is little choice between Y or △ without a grounded neutral.

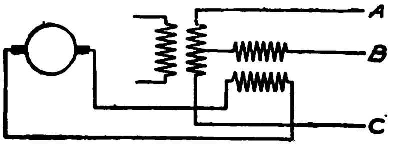


Fig. 5

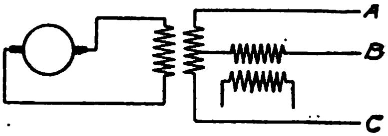


Fig. 6

In small installations, the cheaper cost of transformers for Y with a grounded neutral will be a determining factor. Larger plants will be guided by the greater importance of giving uninterrupted service and will not employ a grounded neutral unless demanded on the score of safety.

Where the amount of power is great and the system extensive, △ connection will be generally preferred on account of its avoiding the possibility of rises of potential from any cause. Many plants can have advantageously a mixed system with both Y and △ transformers, each installation of transformers being considered by itself.

[CONTRIBUTION TO DISSCUSSION ON F. O. BLACKWELL'S PAPER BY J. S. PECK.]

MR. J. S. PECK:—In his paper, " Star or Delta Connection of Transformers," Mr. Blackwell refers to the grounding of the neutral points of a transmission system, for the purpose of limiting the strain between line wires and ground, and mention is made of the fact that the neutral point is likely to drift out of position and cause unequal voltage strains upon different parts of the circuit.

The question of grounding or not grounding the neutral and of the best method of connecting transformers is one of great importance, and it is the object of this paper to point out some of the conditions, both normal and abnormal, which arise with different systems of connections with and without grounded neutral.

By the grounding of the neutral point of a transmission system it is sought:

First:—To limit the strain from line wires to ground.

Secondly:—To limit the strain between high-tension and low-tension windings of the transformers, also between high-tension windings and iron core.

There are a number of different ways of connecting transformers for transmission work:

Single-phase, 2-phase, 3-phase-delta, 3-phase-T, 3-phase-V 2-phase-3-phase, 3-phase-star, 3-phase-star-and-delta.

Consider first the case of a single-phase transformer ungrounded, with high-tension and low-tension voltages taken for convenience as 10000 and 1000 respectively, (see Fig. 1). There is evidently a maximum strain of 10000 volts from one high-tension line wire to the other. If the circuits are insulated and symmetrical there will be a strain of 5000 volts from each line wire to ground, and from each extremity of the high-tension winding to the low-tension winding and to the iron core.

If, however, the circuits are not symmetrical, the full strain will not be equally divided, and if in an extreme case one high-tension wire is grounded there will be a strain of 10000 volts from the other line wire to ground; similarly, if one extremity of the high-tension winding be connected to the low-tension winding or to the core, there will be a strain of 10000 volts from the other extremity of the high-tension winding to the low-tension winding or to the core.

The actual strain between adjacent high-tension and low-tension windings is equal to the high-tension voltage plus or minus the low-tension voltage, depending upon the arrangement and connection of the coils; but as the low-tension voltage is usually a small percentage of that of the high-tension, it is customary to assume that the strain between windings is equal to that of the high-tension voltage alone.

If the middle or neutral points of high-tension and low-tension windings are grounded, the iron core being also grounded (see

Fig. 2), then as long as the circuits are in balance the voltage strains will be the same as with the windings ungrounded, and balanced; but in case of a ground on either high-tension or low-tension line, or in case of a connection between high-tension and low-tension windings, a portion of the windings will be short-circuited. This will, in general, blow fuses or open circuit-breakers, thus cutting the transformer out of service; or the voltage of the system will be lowered to such an extent as to call attention to the trouble.

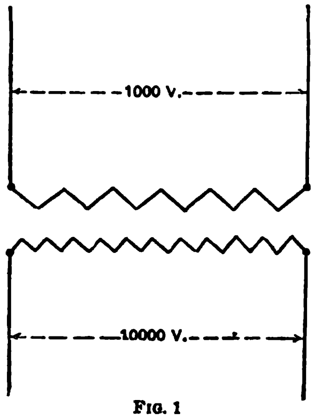


FIG. 1
Single Phase
1000 to 10000 volts
Maximum Strain to Ground
10000 volts

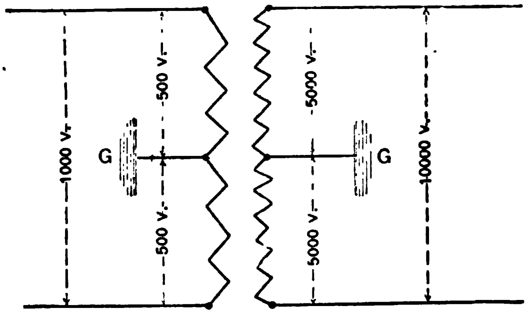


FIG. 2
Single Phase Grounded Neutrals
1000 to 10000 volts
Maximum Strain to Ground
5000 volts

Thus, on a single-phase transmission system, the grounding of the neutral point of primary and secondary windings will limit the strain from line to ground, and from either extremity of high-tension to low-tension and iron to approximately one-half the normal voltage of the system. If the neutral of only one winding is grounded, the strain from this winding to ground will be limited to approximately one-half of its normal voltage, but the strain from the ungrounded winding to ground and to iron and to the grounded winding will not be thus limited.

In considering other systems, the voltage strains between primary and secondary will not be mentioned, as these strains are easily calculated when the voltage on the transformers and the strain to ground is known. A short-circuit on a system will be assumed to cut out the trasformers.

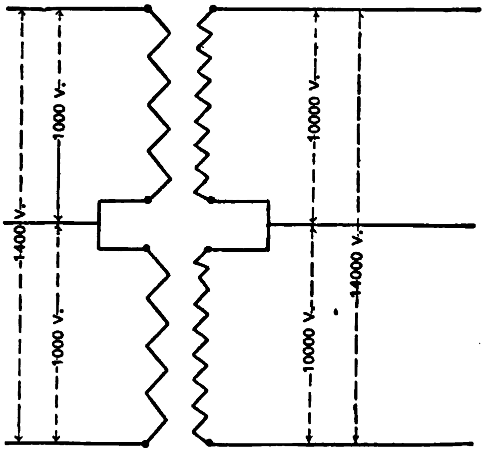


Fig 3
2-Phase - 3-Wire
1000 to 10000 volts
Maximum Strain to Ground
14000 volts

Two-Phase, Four-Wire System.

The 2-phase, 4-wire system is practically a double single-phase system, and the conditions for grounded and ungrounded neutral will be the same as for single-phase.

Two-Phase, Three-Wire System.

The voltage across the two outside wires is 1.4 that between the middle and either outside wire. The connections and voltages are shown in Fig. 3, which assumes 1000 to 10000 volt transformers.

A ground on the middle wire will give a strain of 10000 volts between each outside wire and ground, while a ground upon an outside wire will give a strain of 10000 volts from middle wire to ground, and of 14000 volts from the other outside wire to ground.

The neutral point for this system may be obtained from the middle point of an auto-transformer connected across the transformer windings. In this case, a ground upon any line wire will cause a short-circuit on the transformers, thus limiting the strain to ground to approximately .7 normal line voltage.

Thus, with a 2-phase-4-wire or a 2-phase-3-wire-system, grounding the neutral limits the strain from line wires to ground, in the first case to one-half normal voltage, in the second case to .7 normal voltage.

In general, the method of obtaining the neutral point by means of auto-transformers is not feasible on high-tension systems on account of the comparatively great cost of an auto-transformer wound for the high-tension voltage, and it will not be further considered in this discussion.

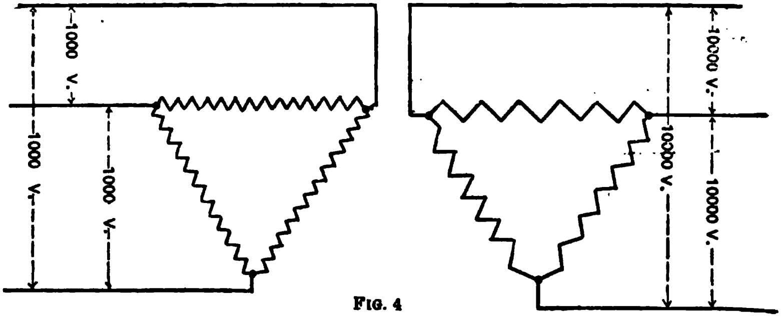


Fig. 4

3-Phase Delta Connection
1000 to 10000 volts
Maximum Strain to Ground
10000 volts

THREE-PHASE, DELTA SYSTEM.

With this system shown in Fig. 4, the strain from any line wire to ground is, with the system in perfect balance, 58 per cent. of the line voltage. In case of a ground on any line wire, the two remaining wires are raised to full line potential above the ground.

With this connection one transformer may be cut out, leaving two connected in V, and the above conditions will not be changed.

THREE-PHASE, "V" SYSTEM.

With transformers connected in V, the strains will be the same as when connected in delta.

THREE-PHASE, "T" AND TWO-PHASE-THREE-PHASE SYSTEM.

With either the T or 2-phase-3-phase connection the voltage strains with ungrounded neutral are the same as for the delta system. The neutral point may, however, be obtained from the teaser winding (see Figs. 5 and 6), in which case a ground upon any line wire will short-circuit portions of the windings.

With the 3-phase-T and 2-phase-3-phase connection the grounding of the neutral limits the voltage between line and ground to 58 per cent. of normal.

STAR SYSTEM.

With transformers connected in star the conditions are very similar to those where two transformers are connected with primary windings in series and also the secondaries in series.

Fig. 7 shows such a series combination, neutral not grounded.

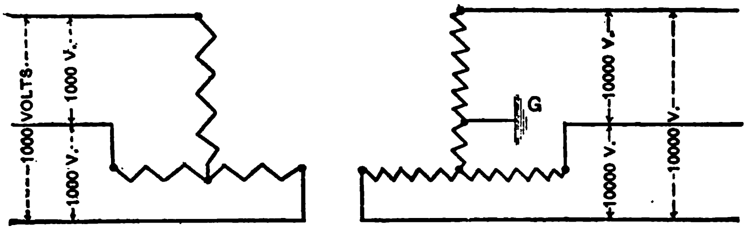


FIG. 5
Three-phase T System. 1,000 to 10,000 Volts. Neutral Grounded.
Maximum Strain to Ground 5800 Volts.

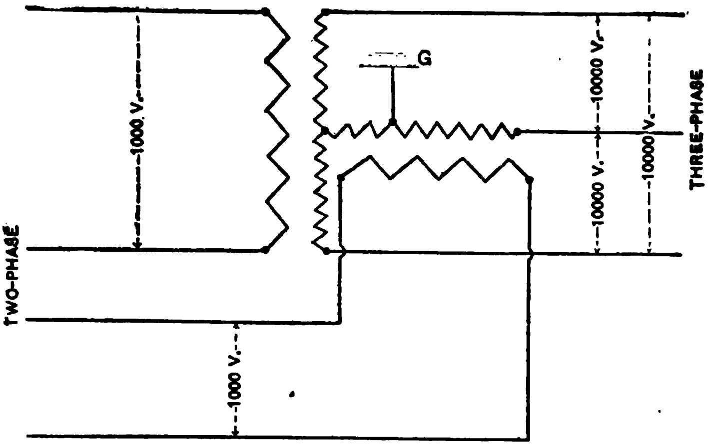


FIG. 6
Two-Phase—Three-Phase System. 1000 to 10000 Volts. Neutral Grounded.
Maximum Strain to Ground 5800 Volts

The total line voltage will divide with approximate quality between the two transformers. Between line wires and ground there will exist the same strain as with a single transformer, having the same total voltage; but if one transformer be short-circuited, the full voltage will be concentrated upon the other transformer so that the internal voltage strains on this transformer will be doubled and its iron loss greatly increased, through the strain from line wires to ground may be the same as before.

If the series connection between the two transformers be grounded (Fig. 8), and a ground occur on either line wire, the transformer connected to this wire will be short-circuited and the other transformer will take the full voltage of the circuit and the ungrounded wire will be raised to full line voltage above ground. Unless the leakage current of the transformer working at

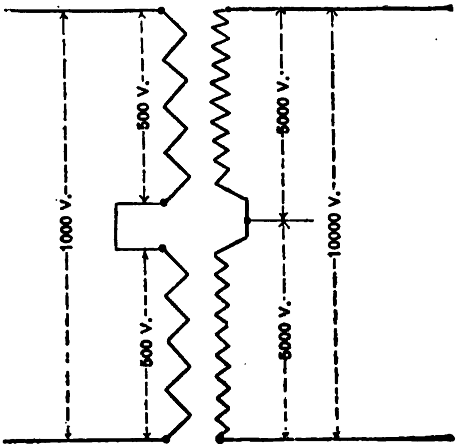


FIG. 7

Two Transformers—1000 to 10000 Volts. Primaries and Secondaries in Series. Each Transformer takes approx. ½ Line Voltage.

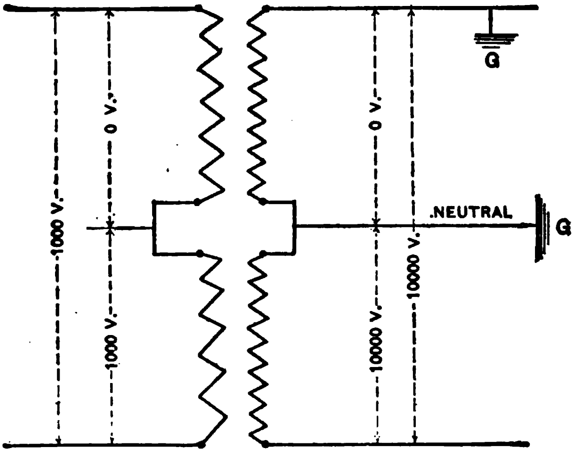


FIG. 8

Two Transformers, Primaries and Secondaries in Series. Neutral Grounded. Ground on Outside Line Wire Short Circuits Adjacent Transformer and Gives Double Voltage on Other Transformer. Full Voltage Strain to Ground.

double voltage is sufficient to open the circuit, the transformer may continue to operate indefinitely under the above conditions provided it does not break down, due to excessive heating or to the double voltage strains to which it is subjected.

In Fig. 9 is shown a star-connected group of transformers with the neutral point of the primary and of the secondary, and also that of the generator, grounded. In this case no excessive voltage can occur on any transformer, and the strain from any line wire to ground is limited to 58 per cent of full line voltage, for a ground on any line or a short circuit in any transformer will short-circuit the generator.

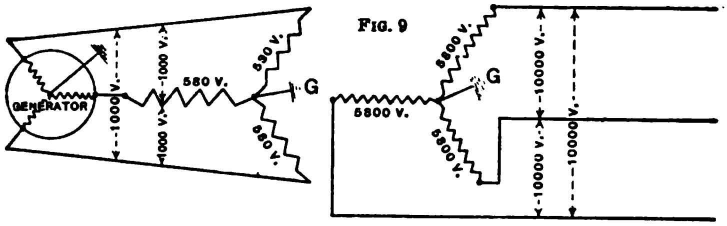


FIG. 9

Three-Phase Star System. Line Voltage 1000 and 10000 Volts. Transformer Voltage 580 and 5800. Grounds on Neutrals of Generator and Transformers. Max. Voltages per Transformer 5800, Max. Voltage to Ground 5800.

Fig. 10 shows the same system of connection but with the generator ground omitted. In this case a ground upon a primary or secondary line will short-circuit one transformer of the group and the two remaining ones will be operated at 73 per cent. above normal potential; also the strain between the ungrounded wires and the ground will be that due to the full line voltage.

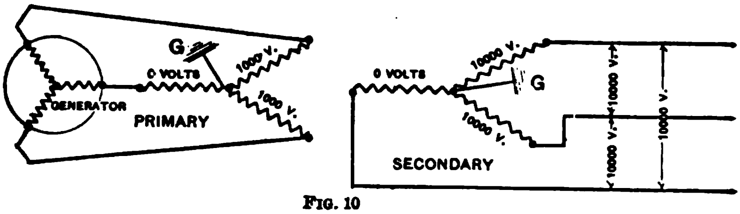


FIG. 10

Three-Phase Star. Primary and Secondary Neutrals grounded. Line Voltage 1000 to 10,000. Normal transformer voltages, 580 and 5800. Ground on one line wire short circuits one transformer, increases voltage on other transformers 73%, raises two line wires 10,000 volts above ground.

Thus for a star connected system the grounding of the neutral points is of no value in limiting the voltage strains on the system unless the neutral point of the generator be also grounded; in fact, the grounding of the transformers without the grounding of the generator increases the chance for trouble, since a ground upon any line wire increases by 73 per cent. the voltage of two of the transformers.

STAR-TO-DELTA SYSTEM.

Fig. 11 shows a star-to-delta system. With this method of connection no excess voltage can be obtained on any transformer, and not more than full voltage strain to ground, provided the delta remains closed; but with the delta open at one point and a short-circuit on one transformer (Fig. 12), the voltage on the two remaining ones will be increased 73 per cent. and across two sides of the delta there will be *three times normal voltage.* Thus, on a 10000 volt circuit, 30000 volts may be obtained in case a transformer is short circuited and cut out of the delta.

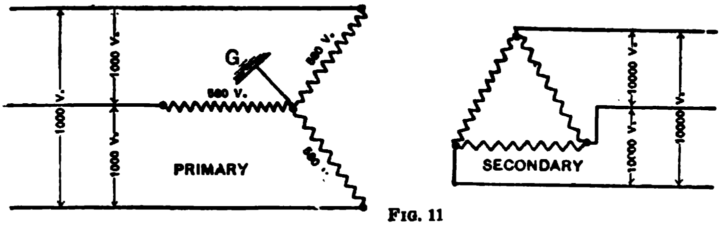


FIG. 11

Star to Delta System.
Line Voltages 1000 and 10000.
Transformer Voltages, 580 and 10000.

This excess voltage across the two sides of the delta is due to the fact that a short-circuit on the star changes the angular position of the voltages from 120° to 60°, which in turn changes the angular position in the delta from 60° to 120°.

DELTA-TO-STAR SYSTEM.

With this system it is impossible to obtain voltages higher than normal upon any transformer or between any two line wires. A short-circuit in one transformer may, however, cut it out of the delta but leave the star-connection intact. In such a case the voltages will be as shown in Fig. 13. Two of the transformers operate at normal potential, with normal potential between two of the line wires, but with 58 per cent. of normal between the other wires.

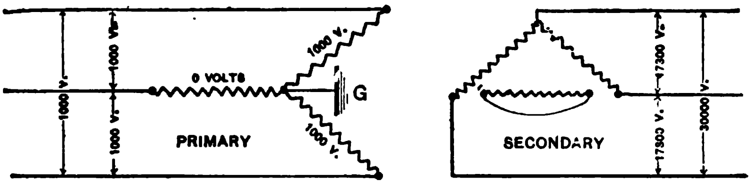


FIG. 12

Same as Fig. 11 except that Delta is opened and one transformer short circuited. Voltage of two transformers increased 73%. Voltage between two line wires increased 200%.

STAR-TO-DELTA, RAISING. DELTA-TO-STAR, LOWERING.

In Fig. 14 is shown a transmission system with raising-transformers connected star-to-delta, and lowering-transformers connected delta-to-star. The voltages obtained across transformers and across line wires are shown. The neutral points of the low-tension windings of both raising and lowering-transformers are grounded, generator neutral not grounded.

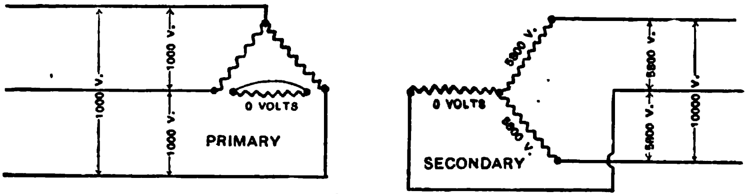


FIG. 13

Three-Phase Delta to Star System. Line voltages 1060 and 10000. Transformer voltage 1000 and 5800 One transformer short circuited and cut out of Delta. Two transformers continue to operate at normal voltage, giving 10000 volts across two line wires, 5800 volts across others.

Fig. 15 shows the voltages which will be obtained with a ground on one low-tension lead which short-circuits one transformer. The high-tension side of this transformer is cut out of the delta. The voltage across the other transformer is increased 73 per cent. and the phase relation changed from 120° to 60°, the voltages being as shown in Fig. 12. On the lowering-delta, three times normal voltage is impressed on one transformer and 73 per cent. above normal voltage on the other two. The voltages obtainable across the star on the lowering-transformers are readily understood from the figure. It will be noted that across one phase there is normal voltage and across the other two phases

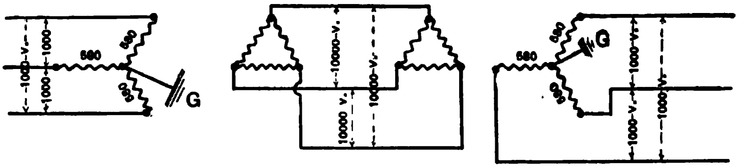


FIG 14

Star to Delta Raising Delta to Star Lowering Neutral of Raising and Lowering Transformers grounded.
Line Voltages 1000 to 10000 to 1000 Transformer Voltage 580 to 1000 to 580.

2.7 times normal voltage. It is probable that a transformer subjected to three times normal voltage would take so large a leakage current as to blow fuses.

With this system of connections, grounding the neutral point of the star without a ground upon the neutral point of the generator is of no use in preventing unequal and excessive strains on the transformers and from line wires to ground. Should the delta on the raising-transformers be kept closed, it is obvious that a short-circuit on any raising-transformer would short circuit the generator, but the above condition is one which might very possibly occur where switches or fuses are placed inside the delta.

DELTA-TO-STAR, RAISING. STAR-TO-DELTA, LOWERING.

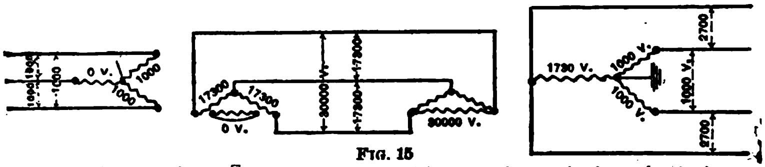


FIG. 15

Same as Fig. 14, except that one raising transformer is short-circuited and cut out of Delta.
Voltages on raising transformer 73% above normal and zero.
Voltages on lowering transformer 73% above normal and 200% above normal.
Voltages on high tension line 73% above normal and 200% above normal.
Voltages on secondary of lowering transformer normal and 170% above normal

Fig. 16 shows voltages obtained under normal conditions with transformers connected delta-to-star and star-to-delta with low-tension and high-tension voltages of 1000 and 10000 respectively.

Fig. 17 shows approximately the voltages and phase angles obtained when one raising-transformer is short circuited and cut out of the delta, but with the star connection intact. The voltages obtained on the lowering-delta will be approximately those shown. It will be noted that this delta has been twisted far out of its normal form, though the voltage on no transformer has been raised above normal and on the lowering-transformer all voltages are below normal.

Fig. 18 shows the same connection but with one lowering-transformer short-circuited and cut out of the delta. The voltage across one of the remaining transformers is increased 73 per cent. while that across the other remains normal. The voltage across the open side of the secondary delta is increased 165 per cent.

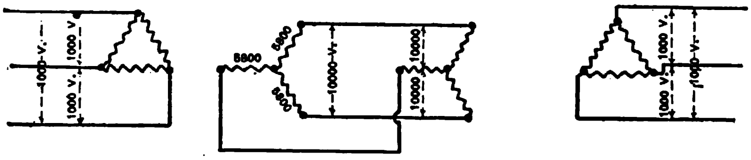


FIG. 16

Delta-to-Star Raising. Star-to-Delta, Lowering. Neutrals not grounded.
Line voltages 1000 to 10000 and 1000; transformer voltages 1000 and 5800 to 1000.

above normal; that on one transformer 73 per cent. above normal and on the other it is normal.

If the neutral points of raising and lowering transformers are grounded the abnormal conditions shown in Figs. 17 and 18 cannot be obtained, for in this case, with the lowering-delta closed as in Fig. 17, the fuses will be blown when a lowering-transformer is short-circuited; and with the delta open as shown in Fig. 18, a short-circuit in the lowering-transformer will short circuit the generator.

Some abnormal conditions which may be obtained from a few of the possible combinations of transformers have been given above. These abnormal conditions are produced by combinations which are accidental or unusual; but it is the accidental or unusual condition which must be taken into consideration and guarded against, if trouble is to be avoided. Some of the conditions which are shown, undoubtedly have occurred in practice and are possibly responsible for some of the troubles on high-voltage transmission systems.

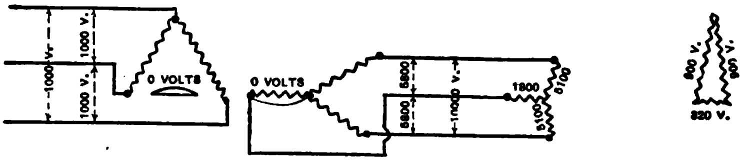


FIG. 17

Same as Fig. 16, except that raising Delta is open and one transformer short circuited. Voltage on lowering transformers less than normal. Note the extent to which the Delta is distorted. If neutral points of raising and lowering transformers be grounded, this distortion cannot occur, as fuses will blow when raising transformer is short circuited.

It is obvious that a large number of combinations of raising and lowering-transformers in addition to those given above may be obtained, and in the following tables it has been endeavored to give the most common of these combinations and to show the abnormal conditions which are obtainable.

Resonance.—The abnormal voltages given above are those which are obtained from the generator pressure through direct transformation. Mr. Blackwell, in his paper, " Star or Delta Connection of Transformers," has called attention to another cause which may produce abnormal voltages, *i.e.*, Resonance. This is particularly liable to occur when a high inductance, such as the winding of an idle transformer is in series with a large capacity, such as that of a transimssion line.

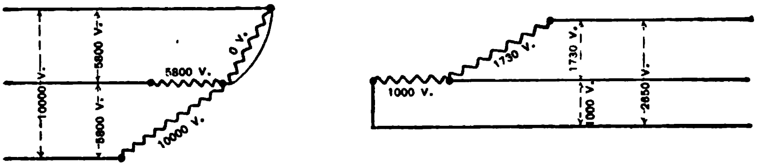


FIG. 18

Same as Fig. 16, except that lowering Delta is open and one transformer short circuited.
Voltages on raising transformers normal and 0.
Voltages on lowering transformers normal, 73% above normal and 0.
Voltages across secondaries normal, 73% above normal and 165% above normal.

In the tables below, where the combination is such as to give an idle transformer in series with an active transformer and a transmission circuit, it is indicated in the column headed "Resonance."

TABLE I.

SYSTEMS OF CONNECTING TRANSFORMERS WITH VOLTAGE STRAINS OBTAINABLE.

SINGLE TRANSFORMATION.

System.	Neutral.	Maximum Voltage.			Possibility of Resonance.
		Per Trans. %	Between Wires. %	To Ground %	
Single-phase or 2-phase-4-wire	(*a*) Grounded.	100	100	50	No.
Single phase or 2-phase-4-wire	(*b*) No Ground.	100	100	100	No.
2-phase-3-wire	" "	100	140	140	Yes.
3-phase Delta. .	" "	100	100	100	No.
3-phase V......	" "	100	100	100	Yes.
2-phase-3-phase or 3-phase T. .	(*a*) Grounded.	100	100	58	"
2-phase-3-phase or 3-phase T. .	(*b*) No Ground.	100	100	100	"
3-phase-Star. . .	Grd. or not Grd.	173	100	100	"
3-phase-Star. ...	Transformer and Generator Grd.	100	100	58	"
3-phase-Star to Delta.......	(*a*) Trans. and Gen. Grd. Delta Open or Close	100	100	100	No.
	b) Grounded Delta Open.	173	300	300	Yes.
	" Closed.	100	100	100	No.
Delta to Star....	(*a*) Grd. Delta Open.	100	100	100	"
"	(*b*) Grd. Delta Closed.	100	100	100	"

TABLE II.

Systems of Connecting Transformers With Voltage Strains Obtainable.

Double Transformation.

System.		Neutral.	Maximum Voltage.					Possibility of Resonance.
			Per Transformer.		Between Wires.		To Grd.	
Raising.	Lowering.		Raising.	Lowering	High Tension.	Low Tension.		
			%	%	%	%	%	
△△	△△	No Grd., Deltas open or closed	100	100	100	100	100	No.
△△	△ Y	" " " " "	100	100	100	100	100	No.
"	YY	Grd. or no grd. Deltas, open or closed	100	173	100	100	100	"
"	Y △	(*a*) " " " " "	100	100	100	100	58	"
"	"	(*b*) " " " open	100	173	100	300	100	"
YY	YY	(*a*) Grd. on all transformers and generator	100	100	100	100	58	Yes.
"	"	(*b*) No grd. on generator, transformer grd. or not	173	173	100	100	100	"
"	△△	(*a*) Grd. on generator and transformers, Delta open or closed	100	100	100	100	58	"
"	"	(*b*) No grd. on generator, delta open or closed.	173	173	100	100	100	"
"	△ Y	(*a*) Grd. on generator and transformers, Delta open or closed	100	100	100	100	58	"
"	"	(*b*) No grd. on generator, delta open or closed.. Trans. grd.	173	100	100	100	100	"
"	Y △	(*a*) Grd. on generator and transformer, delta open or closed	100	100	100	100	58	"
"	"	(*b*) No grd, on generator, grd. on raising. Delta open	173	173	100	300	100	"

TABLE II.—Continued.

System.		Neutral.	Maximum Voltage.					Possibility of Resonance.
			Per Transformer.		Between Wires.		To Grd.	
Raising.	Lowering.		Raising.	Lowering	High Tension.	Low Tension.		
			%	%	%	%	%	
△ Y	△△	(*a*) Gr. deltas open or closed	100	100	100	100	58	Yes.
"	"	(*b*) No grd. Deltas open or closed	100	100	100	100	100	"
"	YY	(*a*) Grd. on all transformers. Delta closed	100	100	100	100	58	No.
"	"	(*b*) Grd. on all transformers. Delta open	100	100	100	100	100	Yes.
"	"	(*c*) No. grd. Delta open	100	173	100	173	100	
"	△ Y	(*a*) Grd. on transformers. Deltas closed	100	100	100	100	58	No.
"	"	(*b*) Grd. on transformers. Deltas open	100	100	100	100	100	Yes.
"	Y △	(*a*) Grd. on transformers. Deltas closed	100	100	100	100	58	No.
"	Y △	(*a*) Grd. on transformers. Deltas closed	100	100	100	100	58	No.
"	"	(*b*) No grd. on lowering on no grd. on raising lowering delta open	100	173	100	300	100	Yes.
"	"	(*c*) Grd. on raising and lowering, lowering delta open or closed	100	100	100	100	58	"

TABLE II.—Continued.

Y △	△ △	(*a*) Grd. on generator and transformer, Deltas open or closed	100	100	100	100	100	No.
"	"	(*b*) No grd. on generator, raising Delta open, lowering delta open or closed	173	300	300	300	300	"
"	Y Y	(*a*) Grd. on generator and transformer, Delta open or closed	100	100	100	100	58	"
"	"	(*b*) No grd. on generator, grd. on transformers, Delta closed	100	173	100	100	100	"
"	"	(*c*) No grd. on generator, grd. on transformer, Delta open	173	173	300	300	173	"
"	△ Y	(*a*) Grd. on generator and transformer, Delta open or closed	100	100	100	100	100	"
Y △	△ Y	(*b*) No grd. on generator, transformer grd. or not Deltas closed	100	100	100	100	100	No.
"	"	(*c*) No grd. on generator, transformer grd. or not, raising Delta open	173	300	300	270	300	"
"	Y △	(*a*) Grd. on generator and transformer, Deltas open or closed	100	100	100	100	58	"
"	"	(*b*) No grd. on generator, lowering Delta open; grd. on transformers	100	173	100	300	100	"
"	"	(*c*) No grd. on generator, raising and lowering Deltas open; grd. on transformers	173	173	300	265	300	"

In the above tables, it has not been attempted to show all the operating conditions with each of the combinations. The remaining ones may, however, be readily worked out.

In addition to the combinations given above there are the 2-phase-3-phase, 3-phase-V and 3-phase-T connections which may be used at either the raising or the lowering ends. When used for raising transformers, these combinations will deliver their proper voltages to the line provided the proper voltages are impressed on their primary terminals, as it is impossible by short-circuiting one transformer to raise the voltage of the other.

When used as lowering-transformers these combinations will supply to the secondary circuits, voltages of proper amount and bearing the proper phase relation to each other, provided the voltages impressed on the primary side are of proper amount and proper phase relation to each other. If, however, the voltages applied to the primary are distorted then the voltages delivered by the secondaries will be correspondingly distorted.

Grounded Neutrals.—It will be noted that in many cases the grounding of the neutral points of a transmission system limits the voltage strain to ground and the voltage which may be obtained across any transformer, and in such cases grounding would seem advisable. This is notable in the case of the star-system with grounds on transformer and generator neutrals. There is, however, a danger arising from this grounding which should be carefully considered. In case of trouble on the circuits, current may flow through the ground to the neutral; in thus flowing it will naturally take the path of least resistance, so that if telephone or telegraph lines, which have normally low resistance to ground, parallel the transmission circuit, the current will flow along these wires, often with disastrous results to the circuits.

Two cases of trouble are particularly liable to give these conditions:

First:—Where the neutral points of the high-tension windings of raising and lowering-transformers are grounded, the opening of one or two of the three transmission wires will cause currents to flow through the ground.

Secondly:—A high resistance ground on a transmission wire will partially short circuit a transformer and cause current to flow through the ground to the neutral.

Some plants have been able to operate satisfactorily with grounded neutrals; with others this grounding has caused great disturbance on telephone circuits, and in one plant it is reported that the blowing of a fuse on one of the high-tension wires put out of service the telephone systems in " ten counties." Thus, while grounding of neutrals may be permissible in certain localities it may not be allowable in others; and in laying out a plant it would seem to be advisable so to arrange the apparatus that it may be safely operated without grounding the neutrals.

An examination of the tables given on pages 401, 402, 403, 404, indicates that the delta-system is the one giving the minimum chance of trouble. Under certain conditions, however, the star and star-delta systems will give satisfactory service.

The choice of a system of connections for any high-voltage transmission system is evidently a matter which should be carefully considered, account being taken of the possibility of obtaining excessive voltages under accidental conditions, the chance of trouble on parallel circuits, due to grounded neutrals, and the possibility of obtaining resonance when switching or under other similar conditions.

President Scott:—The question of grounding one point of a transmission line is a very important one, and it is one which has received a good deal of attention during the last few years. I remember when some engineers with whom I was acquainted went West to visit transmission plants, I asked them to look into that point particularly, and from the evidence which they got, and from the evidence that I obtained when I took a trip West some time ago, and from what I have heard since, I have concluded this—that some plants grounded the neutral, and its engineers considered it safe and would never think of running in any other way, while the engineers of plants which did not ground the neutral would never think of doing such a thing. It is an important question; it is partly theoretical, it is largely practical and one which is not yet settled. We should like particularly to hear from out western friends on this point. The subject is open for discussion.

Mr. Hayward:—As you say, Mr. President, this has been a subject of discussion for a good while, as to whether to ground or not to ground, and our friend Mr. Nunn has been operating his lines grounded from the very start, but I believe Mr. Gerry is operating without ground. We, with our 16,000 or 17,000 lines, have operated with a double delta connection without any grounds on. The experiences we have had without grounds are, of course, that you may have a short circuit on one wire, and the wire down, and you could still keep running. Still, I believe—and this is only an opinion—that when we get up to any very high voltage, after all it is better to ground the neutrals and keep them grounded everywhere. It is better, I think, to avoid any chance of these extra high voltages that may occur, and I want to say very emphatically that they have occurred in practice, where some of the conditions mentioned by Mr. Peck and some mentioned by Mr. Blackwell have held. I therefore think that it is probably best to ground every neutral point. We are changing from a delta-delta connection to what will be a Y to delta connection and various other connections which we have not been running hitherto, simply because we are changing our voltage on the high tension lines from 16,000 to 28,000, and we intend to change our distribution in Salt Lake City from 2,300 volt to Y-connected 3,800 volt. Of course, we all recognize the difficulty of a single short circuit on a line with grounded neutral —or single breakdown on the line with grounded neutral—

means short circuit. Yet, after all, we have to recognize this, that our lines must be made so that they will not break down. There is just one point—the rise of potential mentioned in Mr. Blackwell's paper, page 388—the conditions holding in Fig. 3 or 4, I don't know exactly which, actually occurred in testing a transmission line in 1897. The conditions were that we had 37 miles of line. We connected the two circuits on the pole line together solidly, making a line out and back of 74 miles. We got a delta-star connection and tried to see what the charging current on the line was. Having tried with the three switches closed, we then thought we would like to see what it would be with only two switches closed; and as soon as we got up to about 25,000 or 26,000 volts an arc jumped across the wires, 12 inches apart. Not only did it do it once, but it did it every time. That is the condition mentioned by Mr. Blackwell right here. If you get the conditions that are laid down here they will occur sooner or later in practice, and they will find out your weak spot.

PRESIDENT SCOTT:—Mr. Gerry, we turn now naturally to you.

MR. GERRY:—I do not know, Mr. President, whether I can add anything of value to this discussion. The selection of either the star or the delta system of connecting transformers is, to a certain extent, a matter of engineering detail. I say this for the reason that I believe satisfactory results can be obtained by the use of a star connection, although not quite as good results as by the use of a delta connection, on a transmission line. The points of advantage and disadvantage have been referred to generally by Mr. Blackwell and Mr. Peck. The points brought out by Mr. Peck are of great interest, but a plant can be arranged in such a manner as to avoid practically all the dangerous conditions outlined for a plain star system. It is possible to provide. switching devices of such a nature that all three transformers will be cut out automatically, at the same time, in case of trouble with any one; or if a ground appear on the system, and this should always be done on a star connected transmission line, even if the neutral be grounded at the generators in addition to grounding at the transformers.

Mr. Peck, in introducing his discussion, says: " By the grounding of the neutral point of a transmission system, it is sought, first, to limit the strain from line wires to ground." Only a short time ago that was considered of great importance as reducing the strains on the insulation of the line. As a matter of fact, that does not limit the possible strain on the insulators to the pressure from wire to neutral. Even with all the neutrals grounded at the ends of the transmission lines, it is possible, owing to the resistance of the ground circuit, to have on the insulators the full line pressure between wires. In other words, even with a grounded neutral at the generators, it is possible locally, at points on the transmission line, to have the same pressure between the ground and any one line, that you have between any two wires of the circuit. Mr. Blackwell, in referring to the advantages of a grounded neutral, in several instances states that in case of trouble, such as a ground on one of the wires, the result will be immediately to open the automatic devices and cut off the transformer coils from the line. Now, the same result can be accomplished with a delta connected system, by means of suitable automatic devices and without throwing a short circuit on the system.

There are a number of operating advantages of the delta connection, one of which I will mention. A transformer may be cut in and out of service, in and out of delta, with very great convenience and with no disturbance of the system, and considerable operating advantage is thereby obtained, especially where the number of transformers is limited. It has just been suggested that one advantage of the star system is that it is possible to put in transformers connected in delta, and afterwards increase the voltage by changing over to a star connection. As a rule, however, I believe it would be better to arrange the switches for delta connection, and accomplish the desired result by double winding the transformers, operating the coils at first in parallel, and later in series.

MR. CONVERSE:—Mr. Hayward referred to the plant of the Telluride Power Company. I have had considerable to do with the transformers of that plant. It is an old plant, at least we consider it so now. I would say that those transformers were built for star connection on a high-voltage and a low-voltage, and we have had some results there. A great many things have happened there, and I would ask Mr. P. N. Nunn, Chief Engineer of the Telluride Power Company, who is here, to tell us something of them.

PRESIDENT SCOTT:—I had it in my mind to call on Mr. Nunn very shortly. Mr. Nunn's work has figured largely in our INSTITUTE, both in papers which have been presented and in discussions from time to time; but Mr. Nunn himself, who has been so intimately connected with a great deal of this high-voltage and pioneer work, has not been very much in evidence. We are very fortunate in having him here.

MR. P. N. NUNN:—In our Utah system, star connected transformers with grounded centers have been the rule, although the initial transmission employed three-phase two-phase step-down transformers.

Transmission difficulties have been chiefly traceable either to outside interference with our lines, or to the opening of circuits, especially by fuses. The line system is rather complex. the main transmission consisting of duplicate three-phase, three-wire, 40,000 volt lines extending from the Provo to the Logan power house, a distance of approximately two hundred miles, through the several markets of Salt Lake Valley. These are divided into sections, and so arranged that a defective section will cut out without interrupting the whole system. Until recently we have been obliged to protect these sections, as well as our generating and substations, with fuses and to switch at the same points with air-brake switches. Neither of these devices has been satisfactory. The blowing of a single fuse is often followed by the blowing of others, sometimes at distant points, and the opening or closing of switches sometimes produces the same result. It seems imperative that all wires of a circuit should be opened or closed simultaneously, and in this respect the automatic triple-pole oil-switches, with time-limit attachment, which are now being installed, should prove invaluable.

The mere opening or closing of circuits may have caused excessive rise of voltage, as we certainly have had at times some abnormal rises. I recall clearly one instance when current jumped a full eight feet from a conductor to the steel framework of the roof of the station. This may have been due to atmospheric disturbances, although there were no indications of lightning.

From the first we found that a ground on one line did not short-circuit the generator, and noticed that the first indication of such a ground was the arcing of the current over the lightning arresters. Investigation of the conditions led to the discovery that we had full line voltage between the remaining lines and ground, which accounted for the disturbance on the arresters, and also full line voltage on the active transformers, instead of the normal 58 per cent. of line voltage. No transformers have ever been burned out due to this condition, and no serious inconvenience has been suffered so far as I know.

This plant has been in operation nearly six years, employing as stated, star-connected, grounded center transformers and on the whole has been, I think, a pronounced success. Whether the difficulties mentioned have been aggravated by the connections of the transformers, or whether we would have suffered less with delta-connected transformers, I do not know.

President Scott:—I would like to ask Mr. Nunn about one point. You have grounded the central point of the high-tension system. Is the central point of the generator grounded primarily?

Mr. Nunn:—The central points of both low and high-tension winding of the step-up transformers are grounded. The generator winding is not otherwise grounded.

Mr. Thomas:—Mr. Blackwell's paper contains a statement on page 388 which I think needs a little further explanation—the last paragraph:

" It is theoretically possible for a potential 100 times that for which a transformer is wound, to be caused by opening the primary switches, etc."

Of course this is true if we neglect all true energy losses in the system, but there is inherently linked with the condition which he speaks of here an energy loss which must necessarily limit this rise of potential very materially. That will probably bear a little further analysis.

The conditions of resonance at normal generator frequencies, as shown in most all these discussions, requires that the leading current to a transformer line pass through a transformer in one winding, the other winding being open circuit The only way it is possible to get a high enough inductance to meet the condition for resonance is by means of iron in the magnetic circuit in the transformer. As we all know, there is a considerable true loss represented by the energy taken by an open circuited transformer—open circuited, I mean, in the other winding. In some designs I have looked over, this true loss is almost as great as the apparent loss, though not quite so great. In other designs the true loss, I presume, may be half as great as the apparent loss. Now, the resonance results from the action of the potential from some generating source, which builds up oscillations in the oscillating circuit. This generator must supply the true loss. If the true loss is nearly half the total apparent energy, taken by the transformer when connected across the mains,—I mean the total energy, now, considering impedance—then if we should by resonance increase to double this true loss by increasing the voltage on the transformer, no higher potential can be built up, because all the true energy supplied by the generator is absorbed. This can be made a little clearer by considering the formula which gives the result of the current in the circuit containing inductance, capacity and resistance when conditions are right for resonance.

$$\text{Resonance Current} = \frac{\text{General Voltage}}{\sqrt{R^2 + \left(p^L - \frac{1}{pc}\right)^2}} \times \text{Sin}\left(p\,t - \tan^1 \frac{p^L - \frac{1}{pc}}{R}\right)$$

This formula states that the current equals the potential applied from the generator, divided by the true impedence of the circuit, which can never be less than the ohmic resistance R. If this allows only double current on normal voltage, resonance can cause no greater rise. Since the ratio between the true loss and the apparent loss of transformers changes materially with changing induction in the iron, and when above saturation the magnetizing current goes up very fast in proportion to the true energy current turns, it follows that perhaps the resonant current may have to increase several times to cause a doubling of the true loss. This suggests another point if you have the proper frequency for resonance, before e.m.f. is applied, assuming normal magnetic induction in the iron of the transformer. Then if resonance builds up the voltage to perhaps three or four times normal potential, the induction of the transformer has also changed very materially on account of the greater magnetizing current causing a great lessening of permeability and a reductio of the inductance as a choke-coil. Consequently the natura frequency, of the generator, which should give resonance wil. perhaps be several times larger than before the rise of potential started. It is thus quite unlikely with this type of choke-coil that resonance would reach a very high value, even if it were not limited by the true loss. However, when the inductance through which the resonance occurred is not denied for a closed magnetic circuit, as in the case discussed, the true loss is a very small percentage of the total apparent energy and no low limit to the resonance rise can be thus assumed.

In regard to static resonance—I mean resonance at very high frequencies, where choke-coils without rim coils might have the proper resonance values—it seems to me there is little danger of a very considerable rise, because, so far as I know, there is no source of continuous, constant value alternating e.m.f. at a very high frequency. Most discharges we get are perhaps oscillatory, but they lose their intensity very rapidly, two or three oscillations, only, probably, having anywhere near the maximum values of potential.

I would like to ask Mr. Mershon, in the absence of Mr. Blackwell, whether Figs. 5 and 6 on page 389 should not show a ground on either line *A* or *C*, or some form of unbalancing. As those stand, I do not believe that resonance can occur. For instance, in Fig. 5, we have the natural tendency when the generator excites the lines for changing current to pass from *B* to *A* and from *B* to *C*, but these currents will be equal if there is no unbalancing, and since they pass in opposite directions, through the halves of that idle transformer, there would be no choking effect except the small amount due to the magnetic leakage of the transformer. In Fig. 6, the natural tendency is, for the charging current to pass from *A* to *C*, and even if the line *B* is connected at the middle point of the transformer, it is naturally at earth's potential and would never receive any charging current at all. Of course, if either line is then balanced or grounded there then appears a condition for resonance. Am I right in this conclusion?

Mr. Lincoln:—Just one point; I was going to mention a number, but Mr. Thomas has got in ahead of me on the others. One point struck me in connection with the statement of Mr. Blackwell, that theoretically 100 times normal potential was possible in a condition of this kind—resonance. In that connection I was very much interested in reading a contribution by Mr. M. I. Pupin, contributed to the Transactions of this Institute in 1893, in which he showed how very difficult it was to maintain resonance with iron circuits. He showed that resonance, where there was no iron in the inductance, was very marked, but as soon as iron was introduced into his coils the difficulty of obtaining resonance conditions became extremely marked and very difficult to obtain; and that same condition would, I think, apply here, where you have iron in the circuit of the choke-coil, and would prevent a rise in voltage anywhere near approaching that stated by Mr. Blackwell.

MR. PETER JUNKERSFELD:—In Chicago we have been operating a 4-wire-3-phase-60-cycle overhead system with a grounded neutral for about three years. The generators are star connected, and the common point is connected to the ground. It has been very successful from the start. We, however, ground in the station only, and do not ground any other point of the primary system. The neutral, on the secondary of transformers, is also grounded.

In our underground system, which is operated at 9,000 volts and 25 cycles, we likewise operate now with the grounded neutral. For the first four or five years' development while the voltage was only 4,500, we had step-up transformers and they were connected in delta, but the next step beyond that was to double the voltage to 9,000 and install line voltage generators, which have been operated with the grounded neutral. There is one thing though that we have discovered, or rather which has been brought to our attention very forcibly. That is, the necessity of doing away with single-pole switches and fuses, and things of that sort. We have nothing but straight 3-pole oil-switches. We have no plug change-overs, or fuses or single-pole switches. Those have all been done away with, and we believe it is very necessary to do so.

I might say that a great many of the conditions that are laid down here by Mr. Peck and Mr. Blackwell, as Mr. Hayward very forcibly brought out, do occasionally occur in practice, and that is something which needs a great deal of attention. As regards the delta or star-connection, in our experience we have found that the number of transformer troubles are after all comparatively few. In six years I can recall only four, possibly five, cases of serious transformer trouble in substations. With the increase in the number of transformer and rotary converter units feeding an interconnected network, we have come to the conclusion that the advantage of having delta-connected transformers in order to be able to cut out one of the bank and operate with two, is not very great. In the earlier history, when our installations were small and few in number, it was an advantage to have the delta-connected outfit, but with a larger number that advantage disappears, and to-day we are installingY-connected 3-phase transformers, the idea being that these transformer accidents occur very rarely, and when they do occur a whole unit is usually shut down, in any event for a short time, and we can then just as well afford to have it shut down until such time when the whole 3-phase outfit can be replaced.

MR. MERSHON:—Mr. Gerry said something in regard to automatic means for cutting banks of transformers free on both sides. That would mean reverse circuit-breakers, and it would mean not only reverse circuit-breakers, but it would mean 40,000 our

50,000-volt circuit-breakers. Mr. Gerry knows something about automatic circuit-breakers for 40,000 and 50,000 volts. I would like to hear from him in regard to that.

Mr. Gerry:—My remarks just now were intended to indicate that with proper arrangements, either the star or delta connection might be used with good results. If star connections are used on high voltage transformers, in fact on any transformers, it is desirable, in order to obtain proper safety, to have devices which will open all three legs of the circuit at one time but if the delta-connection be employed, you may use single-pole switches. For this and other reasons, up to the present time, I have always considered that there were advantages in using a delta-connected system. Single transformers may be conveniently switched into and out of service; single-pole switches may be employed if desired and at the same time all those excessive potentials mentioned by Mr. Peck will be avoided and resonance will not be likely to result. In other words, a plain delta is at once a flexible and safe arrangement to adopt.

In reference to high-tension circuit-breakers for transmission lines, the time is coming, if it be not here already, when an oil-switch can be obtained, together with reverse current and overload operating devices for any voltage and capacity, which will open all three legs of a circuit. Mr. Nunn touched upon this subject just now, and it is of great importance, especially with a star-connected system. Whether the star connection is the more desirable is another question, but I do not consider it vital in connection with operation, if proper precautions are taken. I do, however, consider the proper arrangement of switches, with either the star or the delta, a very important problem in connection with the system.

Mr. A. L. Mudge:—Page 386, lines 16 and 17, the words "And the other two still deliver 3-phase power up to their full capacity, *i.e.*, two-thirds of their bank," should read, I think, as follows: "And the other two still deliver 3-phase power up to 86.6% of their full capacity, *i.e.*, 57.7% of their entire bank."

Mr. J. E. Woodbridge:—The special case of high-tension distribution of power for the operation of rotary converters brings up some considerations not mentioned in Mr. Blackwell's Introduction.

In distribution of this kind the secondary voltage of the step-down transformers is so low that there is no advantage in a Y-connection of the secondary coils. In fact, this would prove a positive disadvantage. For this reason a delta connection of the secondary windings is to be preferred for 3-phase converters. With the primary windings connected Y and the secondaries delta, operating synchronous machinery, there is no instability of the neutral. While it is true that a Y-delta connection of three transformers with no neutral lead throws the whole bank out of service if one is disabled, the grounding of the high-tension neutral of both the step-up and step-down banks gives a radically different condition. With this connection one transformer of the three may be taken out of service and the remaining two will continue to deliver 3-phase current just as will two transformers connected delta-delta on a 3-phase system. It will be noted that when one transformer on a Y-delta connection with grounded neutral is taken out of service, one of the three line wires is also open-circuited. Thus not only does this connection allow service to be resumed with one transformer crippled, as soon as this transformer can be disconnected, but it allows service to be continued with one line wire in trouble, either broken, crossed with another wire, grounded or attached to a punctured insulator. It has often been claimed for the delta-delta connection of transformers that the ability to operate on two in case of trouble with the third is a great advantage. There are now in operation in this country many railway distribution systems with lines of moderately high-tension, 10,000 to 15,000 volts, put up on trolley-supporting poles along the right of way, which frequently is the public highway, with many trees and many turns, and lacking the substantial and carefully worked out details of the lines of heavy transmissions. These railway distribution plants, so built, are subject to unavoidable line troubles many times more numerous than transformer breakdowns. It seems to the writer that any connection of the transformers which allows operation with one line wire in trouble is much more valuable in such cases than any which simply provides for transformer troubles.

The drop on a 3-phase line with grounded neutral is increased just 50 per cent. when one line wire is thrown out of service, the other two being used on Y-delta connected transformers; this being based on the assumption that the ground or track return has a negligible resistance in the high-tension transmission. The writer has operated a railway substation in this way on two wires, starting a rotary converter as an induction motor by means of alternating currents applied directly to its armature, and carrying the load with two wires in service with no apparent difference in the operation from the usual results obtained with all three wires in service. In fact, much to the writer's surprise, there was no apparent effect on the telephone line which was on the same poles with the high-tension line for several thousand feet, one of the three high-tension wires being completely disconnected at both ends. At one time while operating in this way the transmission line became reduced to one active wire and ground, owing to the melting out of a temporary low-tension connection. The substation continued to carry its load and the trouble was not noticed for some time.

It is also of interest to note in this connection that 6-phase rotary converters supplied from diametrically connected transformers will start and carry load satisfactorily when supplied with power on two diameters only. With a Y diametrical connection of the step-down transformers and with a grounded neutral the cutting out of one transformer would of course reduce the supply of the 6-phase converter to two diameters. It is almost needless to state that a 6-phase converter with double-delta low-tension connection would operate satisfactorily on two transformers.

Referring somewhat more in detail to the advantages and disadvantages of a grounded neutral, an investigation of the action in case of a punctured or broken line insulator is of interest, as most of the serious line troubles come from insulator breakdowns causing the burning off of cross-arms or pole tops which frequently results in complete shutdown. With no ground on the neutral, the puncturing of an insulator generally manifests itself as a ground on the system. To guard against burning of cross-arms or poles, it is possible to solidly ground the faulty phase, thus removing all electromotive force from the faulty insulator, but this method seems open to the objection that if one insulator will break down under the Y voltage of the system, it is inadvisable to subject two-thirds of the total number to nearly twice this voltage. Some lines are now being built with a fourth wire with switching arrangements at each end of same, so that in case of trouble on one wire the fourth can be connected into circuit in place of the faulty conductor. With a grounded neutral the question arises whether a broken insulator would cause sufficient leakage to open the circuit through overload, or would burn off cross-arm or pole-top without giving previous notice to the station attendants. A ground wire on the poles electrically connected to an iron pin in each insulator would make a short circuit of each insulator breakdown, and would prevent burning off of pole tops. With instantaneously acting autometic switches it would also prevent what is sometimes worse, *i.e.*, the burning apart of transmission wires and dropping of same across other circuits or to the ground.

Another factor that is affected by the grounding of the neutral is the protection against lightning. On a line with no ground of the neutral it is essential to have enough gaps to prevent a discharge under the full rated voltage between wires. This voltage is applied when one corner of the circuit becomes grounded. It is also necessary to provide enough resistance in each branch of the discharge path to prevent an arc holding when a discharge occurs under this voltage. With grounded neutral the maximum voltage between any one wire and ground is reduced nearly 50 per cent., allowing material reduction of the number of gaps and resistance in the discharge paths.

From the above consideration the writer believes that extra high voltage systems, that is, those with working pressure between wires of over 25,000 or 30,000 volts, should have the high-tension windings of their step-up and step-down transformers Y-connected with the neutrals grounded.

(COMMUNICATED AFTER ADJOURNMENT BY DR. LOUIS BELL.)

NOTE OR MR. BLACKWELL'S PAPER.

It should be noted that the Y systems, which are immensely valuable in saving copper, also entail some additional care, as is the case with all copper-saving connections. In practice I have found that mixed delta and Y connections are desirable and tend to steady the regulation. I believe in the grounded neutral as a safety measure, but sources of accidental grounds should be followed up rigorously and carefully eliminated. In using Fig. 1, this is especially necessary, and it is a good thing to ground through light fuses or lightly set circuit-breakers, but one usually has to ground this system since its main use is in making long runs where high voltage lines are barred, and the Fig. 1 connection carries one below the prohibitive restrictions placed arbitrarily to allow old arc machines to run while blocking modern distributions.

(*After Recess.*)

PRESIDENT SCOTT:—We will now descend from the air above to the earth beneath and take up underground work.

We will first have the paper by Mr. Fisher, of the Standard Underground Cable Company, " Electric Cables for High Voltage Service."

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 1, 1903.

ELECTRIC CABLES FOR HIGH VOLTAGE SERVICE.

BY HENRY W. FISHER.

In the early part of the last decade there was a general belief among electrical engineers that rubber-covered cables would be used almost exclusively for high-voltage service and paper-insulated cables for comparatively low voltages. With the improved manufacture of the latter, opinions have changed so that some engineers prefer paper to rubber, stating that in their experience the life of paper cables is longer than that of rubber cables. To account for this they believe that the strain caused by very high voltages gradually deteriorates the rubber by some kind of electrolytic action, or by a purely physical action, or by a tendency for static discharges gradually to penetrate farther and farther until a breakdown occurs. In substantiation of their claims they give instances where rubber cables have broken down one after another in service without any apparent cause. On the other hand, there are engineers who claim that they have operated rubber cables at high voltages continuously without any trouble. The ability of a rubber-insulated cable to withstand high voltages depends upon the ingredients entering into the composition of the rubber compound. The dielectric strength to resist electric pressure becomes greater within certain limits with increased percentages of pure Para or other high-grade rubber; and there is good reason for believing that when lead-covered cables are employed, the life of rubber-insulated cables is lengthened with increased percentages of such rubber. This subject should naturally be treated under three headings

First: Manufacture of cables.
Second: Installation of cables.
Third: Operation of cables.

First: *Manufacture of Cables* —In the manufacture of paper-insulated cables for high voltages, great care has to be exercised in selecting the right kind and quality of material, and also in the methods of construction and impregnation of the paper with insulating compound. The most experienced engineers now realize that cables saturated with oily compound can better be handled without injury to the dielectric, and also resist better high voltages. The use of oily compound is, however, accompanied with lower insulation resistances, and consequently many engineers who think they are adopting the best practice by specifying several hundred megohms per mile, are in reality inviting bids on an undesirable type of cable. The best cables either with paper or rubber insulation should be able to resist comparatively high voltages for an extremely short period of time. Such voltages are obtained at the time of making or breaking the circuit, or during short-circuits. To illustrate: If a cable of inferior material and construction be subjected to a gradually increasing voltage till a breakdown occurs, and then after removing the burnt-out part the operation be repeated, a second breakdown will almost invariably occur at much lower voltage than at first, showing that the cable was injured by an impulsive rise of voltage at the time of the first burn-out. With the best cables the difference between successive voltages applied as above is much less than is the case with inferior cables, and at the same time the former withstand very much greater voltages for the same thickness of insulation. If the question of expense is not a consideration, paper insulated cable can be made of remarkable dielectric strength. On one occasion the writer designed such a cable with a thickness of insulation capable of ordinarily withstanding 16,000 volts. Extraordinary care was exercised in the manufacture of this cable, and when tested 48,000 volts were required to break it down, and during successive tests the voltages applied scarcely varied 1,000 volts from the above figure, showing a very great uniformity. Such a cable would have a greater dielectric strength than that of ordinary rubber cables, and at least equal to that of rubber cables with high percentages of Para, and would cost fully as much as the latter.

In the manufacture of rubber cables, care has to be used in selecting the best and proper materials; and the work of mixing them and masticating and appyling the rubber must be done uniformly well, and the process of vulcanization must be carried on at the right temperature and for the right length of time to suit the particular compounds. After being made, all high voltage cables should be subjected to the usual test for insulation resistance and electrostatic capacity, and also to voltage tests of double the normal working e.m.f. Even if this test is not specified the manufacturer should apply it for his own protection.

Second: *Installation of Cables.*—This work must be done by well-trained men, as a small amount of carelessness may mean much trouble and expense. When the cables are pulled into ducts great care must be exercised to prevent abrasion of the lead cover, and no sharp bends must be made because in so doing the insulation may become injured or cracked. It is advisable not to pull paper insulated cables into ducts during extremely cold weather, because of the possibility of cracking the insulation. If such work of installation has to be done, the reels of cable should be kept in a warm place over night, or else put under a tent for a few hours and kept warm with plumber's furnaces placed so as not to overheat the cable at any point.

The work of jointing the cables must be done by good jointers who are in turn carefully watched by an experienced foreman. Different companies make different forms of joints, but after a reliable one is adopted the work should be systematic and according to definite directions in all particulars. By so doing, remarkable records of perfect workmanship have been made. After complete installation each cable should be subjected to double the working voltage, but this voltage should not be applied or broken suddenly because by so doing unnecessary strains would be imposed upon the cable.

Third: *Operation of High Voltage Cables.*—This is a subject that could better be presented by the operator of the electric light and power plants where cables are employed. However, as one of the objects of this short paper is to invite discussion, it may be well to state that a perfect protective device for cables and auxiliary apparatus would lessen to a very large extent the troubles of the operator incident to impulsive rises of voltage from switching and short-circuit. On several occasions and in different power houses, discharges have been seen to take place over the surface of switchboards at the time of short-circuits in cables, transformers, switches, etc. On some of these occasions the rise in voltage necessary to make said discharges was estimated to be about four times the normal working voltage. At such times the original cause of the trouble cannot always be ascertained because frequently cables are burned out in several places, and transformers and apparatus injured at the same time. This kind of phenomena seems to be more prevalent and dangerous where air-lines connect with cables. It will therefore be seen that an efficient device which would protect cables and accessory apparatus from such excessive rises of voltage would be of incredible value to operators.

The question of the carrying capacity of cables is often not considered as carefully as it should be. With a great many cables all carrying normal currents are in one duct-system, the middle and top ones are apt to become very warm. The difference between the temperature of the conductor and that of the duct may be nearly as great as the difference between the temperature of the duct and that of the surrounding air, although generally speaking the former is the least. The carrying capacity of cables as frequently recommended is entirely too great when many cables are in the same duct-system.

There is a very great differenec in the radiating power of dry and wet-ducts, and in the heat conductivity of different soils, and so it is impossible to give set rules governing all cases. Under no circumstances should the temperature of the conductor be allowed to reach 90° Centigrade; and if twice the maximum difference of temperature between any duct and earth added to the temeprature of the earth is nearly equal to 90° there is reason for apprehension.

The above remarks do not apply to rubber covered cables, which should never be heated to over 65° or 70° C.

Moreover it is not desirable nor economical to heat paper insulated cables to 90° C., and the only reason for mentioning this figure is because such cables can withstand this temperature for a considerable length of time without deterioration.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 1, 1903.

THE OPERATION AND MAINTENANCE OF HIGH-TENSION UNDERGROUND SYSTEMS.

BY PHILIP TORCHIO.

The following notes apply mainly to moderately high-tension systems as installed in large cities in the last few years.

(1) INDEPENDENT VS. PARALLEL OPERATION OF FEEDERS AT SUBSTATIONS.

By proper selection of size of feeders and transforming units at substations, each feeder can be operated to supply normally an independent group of transforming apparatus. In case of emergency the same apparatus can be arranged to be fed from other feeders through an emergency bus. This arrangement of independent operation of feeders has in most cases the disadvantage of not allowing the full use of the copper investment at light loads, but it has the following advantages.

(*a*) The short-circuit current fed back from the substation bus bars into a faulty feeder is limited by the reactance of at least two sets of transforming apparatus. This will materially help the final clearing of the short-circuit.

(*b*) In rotary converter substations the independent groups of transforming apparatus can be fed from different bus bars or from different generating stations, thereby increasing the reliability of service.

(2) TESTING OF CABLES.

(*a*) Periodic insulation tests are valuable as they furnish indications of abnormal conditions and often lead to the detection of faults on the systems. The instruments usually used in connection with insulation tests are a D'Arsonval galvanometer with shunt, and a battery of from 70 to 100 volts. Periodic tests should be made at least once a week on each feeder, and oftener under abnormal conditions.

(*b*) High-voltage tests of dielectric strength of insulation should be carefully applied or possibly avoided entirely. Experience has demonstrated that failure of cable feeders are almost uniformly due to defective joints or mechanical injury to the cable. The record of all high-tension cable faults of a New York company for a period of five years is as follows:

LOCATION OF FAULTS ON HIGH-TENSION CABLES.

Made manifest by opening of circuit-breakers during operation.	Made manifest by low insulation test.	Reported by Line Inspectors.
1 in splice.	1 in splice.	1 injured in manhole by arc cable burnout.
1 nail driven into cable (external mech. injury.)	1 in splice.	
1 in sharp bend in manhole.	1 in splice.	1 damaged in manhole by A. C. lighting cables burnout.
1 in damaged sleeve (external mech. injury–cause unknown.)	1 leak of steam to cable end.	
1 in bend in small manhole.		1 damaged by outside parties doing subway work.
1 wet end of cable (external injury due to water leak.)		1 damaged as above.
1 wet end cups caused by steam (external mechanical injury.)		1 damaged as above.
1 steam in substation (external mech. injury.)		
1 in splice.		
9	4	5

Note that of the nine faults made manifest during operation, five were due to extraneous mechanical causes and four to defective installation.

The operating voltage of this system is 6,600 volts.

The lengths of high-tension cables in operation on December 31st of the first and last year covered by the record were 3.2 and 84.6 miles, respectively. The cables of this company have not been subjected to high-pressure test in subways.

This table shows that only four cable breakdowns out of 18 faults on high-tension cables could possibly have been prevented by having applied high-pressure tests to the cables originally. It cannot be determined how successful such tests would have been in other respects, as the testing strains might possibly have lowered the dielectric strength of the insulation at points otherwise perfectly safe for operating at the normal pressure. Note must also be taken of the fact that no failure of the cable proper has yet been recorded in this large system, now operating over 85 miles of high tension cables.

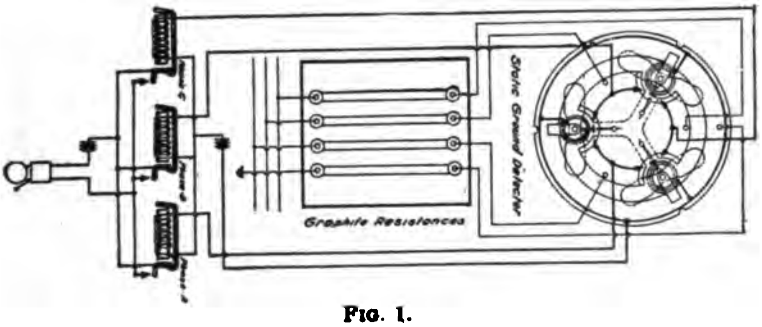


FIG. 1.

(3) INDICATORS AND PROTECTING DEVICES.

(*a*) Ground detectors with annunciator relay and drop-signal are desirable features of a high-tension switchboard equipment. The diagram (Fig. 1) shows an arrangement for a three-phase installation.

(*b*) Grounding of the neutral of high-tension generators is advocated by many engineers, and apparently it has given satisfaction wherever it has been tried. The objection to the heavy short-circuit current from one leg to ground has been overcome by the suggestion of grounding through a non-inductive resistance, thereby limiting the short-circuit current to a pre-determined amount. The experience of the companies so operating will be of great value.

(*c*) SPARK ARRESTERS.—It seems impossible always to guard against the appearance of high voltages due to sudden change of load, grounds, short circuits, etc., and, especially in the latter case, spark-arresters will greatly increase the safety. These devices are preferably connected " delta " on systems without grounded neutral and installed at the generator end as well as substation end of every cable and at every other place where the cable is looped into a substation or joins an overhead line.

(4) APPARATUS AND METHODS FOR CARE OF CABLES.

A new cable should not be connected to the main bus bars without being previously tested with full working pressure. This is sometimes accomplished through a suitable transformer properly fused or by inverting a rotary converter with a fuse on the low tension side.

A defective feeder often requires the application of high-voltage for breaking down the defective insulation and creating a low-resistance path for sending through it a direct current for the purpose of locating the fault by the compass method applied to the cable in successive manholes. To break down and charge the insulation requires about two amperes for paper and five amperes for rubber-insulated cables, applied for about five minutes. The regulation of the amperage could very conveniently be obtained by the use of a reactive coil, or what amounts to the same, a transformer of sufficient internal reactance to limit the current on short-circuit. But while there may not be much danger of resonance phenomena when using reactive coils, still there is some danger and it is, therefore, safer to limit the short-circuit current by resistance. Fig. 2 shows the connections of a rheostat intended to limit the short-circuit current to 2½ and 5 amperes at 6,600 volts.

(5) RULES.

In a large system it is important to devise a set of rules for the guidance of the men in the different departments. These rules must be rigidly complied with so as positively to eliminate any danger to men making tests or repairs to cables or switchbards.

(6) MAINTENANCE.

It is not feasible to estimate accurately the life of high-tension cables and what will be the cost of maintenance after several years' installation. The cost of repairs for the first years is merely nominal, and the only other items of maintenance are the expenses for the periodic inspection and testing and minor details.

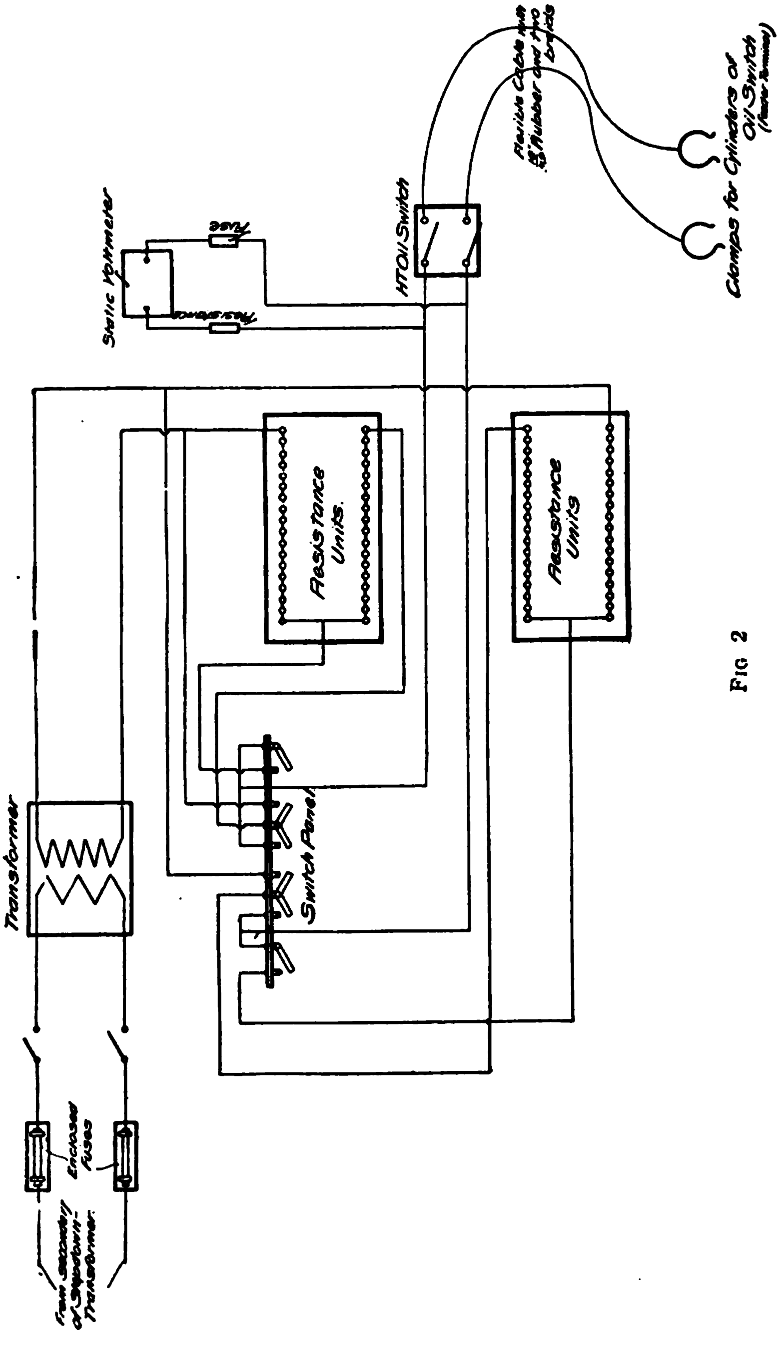

Static Voltmeter
Fuse
Resistance
H.T. Oil Switch
Flexible Cable with .8" Rubber and two braids
Clamps for Cylinders of Oil Switch
(Power Terminals)
Resistance Units.
Resistance Units
Transformer
Switch Panel
From Secondary of Step-down Transformer.
Enclosed Fuses

FIG 2

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 1, 1903.

THE USE OF AUTOMATIC MEANS FOR DISCONNECTING DISABLED APPARATUS.

BY H. G. STOTT.

This subject may preferably be divided into three sections, as follows:

(*a*) Generating apparatus.
(*b*) Transmission apparatus.
(*c*) Receiving apparatus.

(*a*) *Generating Apparatus.*—That no overload device should be used in the generating plant to disconnect disabled apparatus may be stated as a general proposition.

Experience has probably been responsible for the evolution of the art to a point where it has become not only possible, but necessary to eliminate all overload devices.

Only a brief statement of the reasons for abandoning the use of overload apparatus will be necessary.

In case of an accident to one generating unit, the other units in multiple with it will immediately begin to force current into the disabled one, and the increased load on the good units, due to their normal load plus the short-circuit current supplied to the crippled unit will, in all probability, trip all the circuit-breakers simultaneously, thus interrupting the service.

Without automatic circuit-breakers the overload on the good units would cause the potential of the system to fall so low that the service would, in all probability, be as completely interrupted as in the former case, unless the attendant succeeds in locating and disconnecting the crippled unit immediately.

Should he fail to do so, the service will inevitably be interrupted, and a great deal of damage done to the crippled unit by the current from the good machines.

It is then evidently necessary to have some means of discriminating between a current coming out of the machine and one going into it. Modern apparatus can safely carry 200 per cent. or more load for a few minutes, but if a unit has become crippled it will immediately cease to be a generator and become a receiver. All that is necessary to do then is to install on each generator a suitable circuit-breaker which will operate *only* when the direction of flow or energy through it is reversed.

This type of safety device has been developed for both D.C. and A.C. apparatus so that it operates quite satisfactorily.

As an additional precaution in large plants, a second reverse-current relay should be installed which will merely light up a letter or number in front of the operator so that in the event of the failure of the first automatic device the faulty machine may be quickly disconnected by hand. These reverse-current relays should have a time-element and current-limit attachment, which should be set for not less than three seconds, so that a slight reverse current, or one of momentary duration, such as is liable to occur at the moment of multiplying, will not operate the circuit-breaker.

(*b*) *Transmission.*—When transmitting power through overhead and underground cables, it is essential to successful operation to be able automatically to disconnect the feeders from (1) the generating station, and (2) if there are duplicate transmission lines, from the receiving station.

(1) At the generating station this should obviously be done by an overload circuit-breaker whose operation is delayed by a time-element which may be set at from one to ten seconds according to the local conditions.

This is all the protection necessary or desirable where only one transmission line exists.

(2) With two or more transmission lines in multiple, an entirely different set of conditions exist as in case trouble develops in one, current will be fed back from the receiver end into the fault through the good feeders; the result will be that all the feeder overload breakers at the generating station will trip, thus shutting down the entire line and, in all probability, shutting down all synchronous receivers on the system, due to the resultant fall in potential.

Reverse-current relays at the receiver end of the feeders operate satisfactorily, provided the fault is not severe enough to drop the potential.

If, however, the fault amounts to a short-circuit the potential at the receiver end will fall so low that the potential coil of the differentially-wound relay will not receive enough current to enable the relay to operate.

Reverse-current relays on the receiving end of feeders are not as yet to be depended upon, but recent improvements give promise that we may soon expect to find a satisfactory solution of this important problem.

When only two feeders are in use a method devised by Mr. L. Andrews, of England, seems to be very satisfactory. At the receiver end the two feeders are connected together through a choking-coil wound entirely in one direction. The current is drawn from a tap in the centre of this winding. Under normal conditions the feeders supply equal current through each half of the winding to the tap, but as the currents pass in reverse direction through the winding the resultant flux is *nil* and, therefore, the resultant inductance is *nil*, the only loss being that due to the ohmic resistance of the coils.

Should a short-circuit occur in one of the lines, the current from the other line will flow through both halves of the reactive coil in the same direction, thus producing a strong choking effect and limiting the current to an inconsiderable amount.

As the overload circuit-breaker on the faulty feeder at the generating station will trip immediately, it is then only necessary for the attendant at the receiving station to open-circuit the section of the reactive coil connected to the faulty cable and short-circuit the other half connected to the good cable. This device, I am informed, has given excellent results in England, but for obvious reasons would not be suitable for more than two feeders.

Where possible, the safest plan at present is, in the writer's opinion, to run the feeders entirely separate at the receiving end, only putting the D.C. end of the rotaries in multiple, or in cases where low tension alternating current (2000 volts or less) is supplied, putting the secondaries in multiple. If, under these conditions, reverse-current relays are installed at the receiving end of the feeders they will operate very satisfactorily as the reactance of the rotaries and transformers will be sufficient to limit the reverse current in the faulty cable, thus allowing the reverse-current relays to operate as there has been no serious fall of potential.

The greater the number of feeders used between the generating station and the substation the better this method becomes, as, for instance, with two cables a fault in one will only reduce the capacity 50 per cent. until the operator can synchronize all the apparatus, which was running on the faulty cable, and as the apparatus and converters will continue to run at full speed only a few minutes will be necessary to synchronize on the good feeder, which will in the meantime carry the whole load, so that no interruption to service will occur. With three cables this would mean a loss of capacity of 33.3 per cent., and with four cables 25 per cent., etc.

(*c*) *Receiving Apparatus.*—This should be treated in exactly the same way as the generating apparatus, namely: use reverse-current relays *only* to operate the circuit-breakers on the rotaries, etc., and use time-element overload relays only on the low-tension feeders leaving the substation.

The above remarks apply generally to both D.C. and A.C. apparatus, with the exception of the part devoted to transmission apparatus, which, of course, only applies to A.C. transmission.

DISCUSSION OF H. G. STOTT'S PAPER ON "THE USE OF AUTOMATIC MEANS FOR DISCONNECTING DISABLED APPARATUS."

BY W. F. WELLS.

MR. W. F. WELLS:—Recent experience with 6,600 volt, revolving field apparatus in central power station practice has proved that automatic disconnective devices are not necessary in order to insure reliable operation of the system to which current is supplied and that capable operators with good judgment can handle any cases that may arise better than automatic devices could be expected to operate.

The instruments and controlling devices on each generator should be placed close together, and their positions so related that there could be no possible chance of the operator when noting the indication on the instrument of one generator, becoming confused and by mistake opening the switch of another machine.

In the station referred to each generator is equipped with an overload relay whose secondary is connected to a red lamp only, and the following indicating instruments, wattmeter, power factor indicator, field ammeter, voltmeter and two ammeters.

The first indication of any trouble is generally a drop in bus pressure, unusual noise from the generators, or lighting up of the overload lamps. A quick survey of the instruments enables the operator to determine if the trouble is on the generators or feeders. If on the generators, the wattmeter or power-factor indicator shows if current is reversed in any one of them, and the field ammeter shows if the reversal is due to open field circuit or loss of motive power. The character of the swing or vibration of the needles will show whether the trouble is due to some accident affecting the angular velocity, such as break in valve motion, or if it is due to faulty governor, cut off of steam supply or broken vacuum.

After a short experience in any such station equipped similarly to the one mentioned, the operator is able almost immediately to locate the cause of the trouble, and if he thinks advisable, open the circuit-breakers before any automatic device would operate, if properly protected by a time-limit element.

During the past eighteen months eight generators have been operated a total of 25,000 hours and a careful anlaysis of every accident or mishap that has occurred has failed to show any necessity or even desirability of automatic disconnective devices. It is almost needless to add that the station was free from accidents that might have been caused by faulty operation of unreliable devices, and there was no expense incurred for maintenance and repairs of such devices.

In the transmission apparatus, it has been found best to set the time-limit overload relays on the feeders in the generating station for two seconds and at about two and one-half times normal load.

During the entire time that the station has been in operation, a period of nearly two years, it has always been the practice to run the high-tension feeders on what Mr. Stott refers to in his paper as the safest plan; *i.e.*, entirely separate at the receiving end, only putting D. C. ends of the rotaries in multiple. But as practically all the substations are equipped with large storage batteries, which are also in multiple with the rotaries, it has been found best to operate without reversed-current relays, but depend on the operator in the substation opening the circuit-breakers when necessary. Here as well as in the generating station, the operators very quickly learn to read from their instruments the nature of the trouble, and the disturbance to the system caused by any accident is always less than it might have been had automatic devices been depended on.

In the substations, the receiving apparatus converts the alternating current to 260 volt direct current and here the only automatic device is an overload-relay on the high-tension feeders, and a centrifugal device which opens both alternating current and direct current switches of the rotary if its speed approaches too close to the danger limit. On the direct current feeders there are no automatic devices.

In general, on the entire system there are in use no automatic disconnective devices except those operated by the time overload relays on both ends of the high-tension feeders, and by the centrifugal speed limit device on the rotaries in the substations.

DISCUSSION OF H. G. STOTT'S PAPER BY MR. CARL SCHWARTZ.

MR. CARL SCHWARTZ:—As to the reverse-current relay for the generator circuit, I think that this relay should operate a lamp and then maybe in addition a bell signal in order to call the attention of the operator, so that he could take as quickly as possible suitable steps to bring the load back to the generator or disconnect this unit if it is unable to work. A reverse-current relay, opening the generator oil-switch, is in that case not very essential and could be left out entirely; but if it is applied it should be provided with a time and current-limit relay. The exciter generator circuit must contain a reverse-current circuit-breaker acting as soon as the generator begins to run as a motor, the supply of the generator field being maintained by a storage-battery.

Referring to the transmission lines, I would say that at the generator end, overload relays with a time limit device will be generally sufficient. It is important that the overload as well as the reverse-current devices for the feeder lines are connected to each phase, as burnouts between one conductor and the lead cover, not affecting the other phases of a three-conductor cable line, may occur. I refer here especially to the star-connected system.

DISCUSSION OF PHILIP TORCHIO'S PAPER ON "THE OPERATION AND MAINTENANCE OF HIGH-TENSION UNDERGROUND SYSTEMS," BY MR. EDWARD P. BURCH.

MR. EDWARD P. BURCH:—Referring to the testing of insulation of high-voltage cables, the writer would add his experience with two very successful 12,000 volt three-phase cables, one 9.5 and one 7.0 miles long, used by a Minneapolis company for three and five years respectively.

Experiments were made on short lengths of these paper cables by stripping off the lead sheath and partly immersing them in water, the full potential being on the three legs of the tri-phase cable. It was found that it usually took several days before water impregnated the paper insulation to such an extent as to cause a short circuit between the legs.

Now most of the cable faults are due to mechanical causes such as a damaged lead sheath or to chemical deterioration of the sheath due to electrolysis from a direct current circuit. In both cases moisture finally, from a day to a week, works through the paper insulation and a cable break occurs. Manhole inspection for the exact location of electrolytic troubles generally proves valueless. Mechanical troubles at or between manholes are generally classed as " accidents."

Tests of value were regularly made on these 12,000 volt cables, using 600 volts direct current. The scheme is to charge the cable legs and then to note the electrostatic discharge through an ordinary Weston direct current voltmeter. The cable terminal switches were of course open at the station and at the substation. If the electrostatic discharge is large, one may safely conclude that the cable is not in bad condition. If the discharge as indicated by the swing of a voltmeter needle, is weak, this is due to the fact that the charge has leaked off through faulty insulation. The indications are, in general, reliable.

In railway power houses regular testing, between 2 and 5 A. M., thus furnished indications of the condition of the cables. It is of some real value to an operator to know that a certain cable is weak and may blow out.

Ground detectors sometimes give negative results. The indications on the scale of the commercial switchboard instrument are too rough to be of great value.

Cable testing sets of the D'Arsonval galvanometer type are generally too sensitive for power station work.

High-voltage tests of cables in service are considered of doubtful value.

DISCUSSION OF PHILIP TORCHIO'S PAPER ON " THE OPERATION AND MAINTENANCE OF HIGH-TENSION UNDERGROUND SYSTEMS," MR. W. G. CARLTON.

MR. W. G. CARLTON:—The experience of the Chicago Edison Company with its high-tension-three-phase cables has been similar to that of the New York Company mentioned by Mr. Torchio. At present they are operating about 45 miles of three conductor cable at 9,000 volts. The first of these cables was installed about five years ago. The voltage used at first was 4,500 but about one and one-half years ago it was changed to 9,000.

There have been seven cases of trouble on these cables: Four were caused by mechanical injuries to cables in manholes; one by a burnout on an adjacent cable; one by a defective joint, and one by electrolysis causing a hole to be made in the lead sheath of the cable. With the exception of the defective joint none of these troubles would have been avoided by using high pressure tests on the cables.

The neutral points of the high-tension generators are grounded direct, no resistances being used to limit the flow of current. Two cases of trouble already referred to, one due to mechanical injury and one to electrolysis, resulted in one conductor of the cable burning to ground, and the other two being left in good condition. One of these cases occurred within 3,000 feet of the generating station. The overload coils on the oil-switch worked and cut out the line. Rotaries in two large substations were running from this line but they merely dropped their load and did not feed back into the cable. Immediately after the trouble occurred the line tested clear and 9,000 volts was applied for about 10 minutes. When the trouble was located it was found that about 6 inches of the copper in one line was gone, and there was an irregular shaped hole in the lead approximately three by six inches.

The second case of trouble occurred about four miles from the generating station and was manifested by a motor generator operating from this line, making a peculiar noise. It was afterwards found that this was due to its running as a single-phase instead of a three-phase motor. The operator at the generating station had not noticed any trouble. One copper was found burned open and there was a hole in the lead approximately the size of a half dollar.

These two cases of trouble are possibly unusual in that very little damage was done. I believe however if we had been operating without a grounded neutral the chance would have been greater for more serious trouble owing to the displacement of the neutral that would have occurred.

PRESIDENT SCOTT:—We shall be pleased to hear from Mr. Eglin.

MR. WM. C. L. EGLIN:—Our experience is different from that of other large companies in that we use a higher frequency and as we started with 60 cycle rotaries before they were properly developed, it necessitated the use of direct current circuit-breakers on the direct side of the rotary converters, for the reason that these rotary converters were installed in stations with storage-batteries and also with other similiar units. With hand operation the current on the direct current side of the rotary would flash over before the operator had time to open the circuit-breaker, and with a large battery in the station it generally resulted in wrecking the rotary, at least wrecking the brush-holders. There were very few of the brush-holders left after that flashing took place; so that we have used circuit-breakers on the direct current side of all rotaries since that time. If we had machines with effective bridges it is possible we would not have used the automatic circuit-breaker on the direct current side of the rotary.

The only other protective device is an automatic speed limit device to prevent speeding up beyond a predetermined speed.

One feature that I feel has not been discussed, and I was sorry it didn't have more discussion in connection with the paper last night, is the limiting of current on the high-tension feeder. I feel that with the growth of the size of generating stations and all of the feeders being run in parallel on a large generating station, we must provide some means for limiting the amount of energy that can be put in to any short circuit of a high-tension cable. Our own practice has been to subdivide the feeders at the substations so that at the substation ends the feeders were not tied together. I think our operation has been much more successful since this has been done. We had conditions similar to those that are spoken of by the high-tension people; that is, that we had the cables break down when they were tied together at the substation end, and a number of other cables would break down for some unexplained reason. Last winter we ran through with all of our cables separated at the other end, and if a cable broke down, that was the end of the trouble; no other cable would break down due to the disturbance in the line during the time of the short circuit.

Mr. Mailloux:—I think that the customer sometimes has to combat the zeal of the manufacturer's sales agent in such matters. The importance of doing away with automatic control of the generators is, I think, such that it should not be under estimated or passed over lightly. It is of great importance in central stations, and it is even of greater importance in relatively large isolated plants. Perhaps the first attempt made to dispense with it in a large isolated plant was in connection with the Astoria Hotel nearly nine years ago. In laying out the plant there I foresaw that it would not do at all to have the machines become disconnected just as soon as we happened to have a little overload, and that it was necessary to resort to some other means of dealing with overloads. We first tried to raise the limit by putting on larger fuses, and we foresaw that cases might occur even where that would not do. We finally resorted to the expedient of putting in an overload-relay, which operated, not to cut out the dynamo but to put on a red light and ring a big bell, the effect being to call attention of all the attendants to the fact that there was danger, while the red light would show the particular dynamo that was overloaded. It was found in practice, however, that even that was not a desirable thing to do, because it might excite a panic. The apparatus is there, but it was never used and they now depend on the operators entirely. There is a man whose duty it is to stand by all the time and see to it that no panic occurs. If there is any overload it is better to let the machine run up to 100 per cent. overload, if necessary, rather than take chances of having a machine become cut out and cause a serious panic. You understand that in a place like the Waldorf-Astoria, where the load is comparable to that of a small town, with from 20,000 to 30,000 incandescent lamps and a motor load varying from 500 to 1,000 h.p., it is a serious matter. I am pleased to say that in something like eight or nine years only one or two interruptions have occurred, and one of those was due to the breaking of a steam pipe.

Mr. Mershon:—I would like to hear further from Mr. Torchio or his representative, Mr. Wells, in regard to a number of points. One is in reference to his statement at the bottom of page 422, that only four cable breakdowns out of 18 faults in high tension cables could possibly have been due to defective installation. As far as anything in the table itself is concerned, it seems to me that nine of the faults there mentioned might have been shown by a voltage test. I should like to ask also whether it is the practice of the Edison Company to install cables and put them into service without giving them any more of a voltage test than one at normal voltage. In regard to the method, mentioned by Mr. Torchio, of keeping each set of apparatus consisting of cables, transformers, and converters separate and distinct until the direct current bus-bars were reached, it seems to me that condition is undesirable because of the fact that you do not get the benefit of your copper on low loads. Under such conditions you must, as your load diminishes and you cut out rotaries, and transformers, cut out also the cables to them so that you keep up to a certain point, a constant load loss on the cables that remain in service. I suppose that if it were possible to obtain a reverse circuit-breaker that could be depended upon to cut out a damaged cable, which would operate under very low voltage or at no voltage—it would be desirable to multiply the cables. I would like to ask Mr. Stott at this point whether he has gotten on the track of any such reverse relay, and whether he thinks there is any chance to have one in the future? His reply will, I hope, bring Mr. Gerry into the discussion, as Mr. Gerry expressed himself a while ago as confident that such device was obtainable. If there is such device I would like to know about it.

I would like to ask Mr. Fisher whether he has made any investigation of the rise in the temperature of cables due to the difficulty of getting the heat from the cable out into the ground; that is to say, as to the fall in temperature that is necessary to force a watt across a given amount of duct and into the ground; whether he has gotten any results which would enable one to calculate, in a duct system, what with a given distribution of load in the cables, the temperature would be of, say, a cable in middle duct. I tried to get some information of that sort a while ago, and went just far enough to get the information that would answer for the particular installation I was about to make. The results were not very full and referred to a conduit consisting of a very few ducts. I should also like to know whether Mr. Fisher has any definite figures on the actual temperature at the conductor which large paper cables will stand continuously without injury?

Mr. Mailloux:—I think that the maximum voltage limit of cables is one of the important questions. I meet with that question constantly in my practice, in cases where one wishes to run overhead but comes to pieces of property where we cannot possibly get the right to run overhead. I have had such cases in districts where rich men live, who seriously object to having overhead wires of any kind pass by or near their properties. In one case it happened that my clients themselves are the people who most objected. They were stockholders of the company, and owned it, and yet, though they understood fully the importance of getting past, they did not want the lines run overhead. In some cases we have had to resort to very expensive underground construction in order to meet that difficulty. Now, as the radius of activity of such a station increases—as the territory expands on the outskirts—it becomes all the more important to be able to raise the voltage. I had a case which was started at 2,000 volts, which was intended to operate over a radius not exceeding two miles. At the end of two years we raised the potential to 6,000 volts and extended the radius to about 10 miles. We are now desirous of extending that radius to 25 miles. I may state incidentally that the station was designed for 500 kilowatts. It is now being transformed into a 6,000 kilowatt station. . This gives you some idea of the growth of the system and of the difficulties which are likely to come up in connection with a station growing under those conditions. The problem with which we are confronted is, to what voltage shall we now step up? We shall probably operate at three voltages corresponding to three zones, a 2,000 volt zone, a 6,000 volt zone, which we already have, and a still higher zone. Now, shall that zone be 12,000, 15,000 or 20,000 volts? It seems to me that it is going to be limited by the limiting voltage at which I can get underground cables which will be reliable for good service. I have been told by some that these cables can be operated successfully at 10,000 volts; by others, as high as 20,000. I should like very much to hear from Mr. Mershon, from Mr. Fisher, and especially from central station men who have had experience with high-voltage cables. What is the highest voltage limit that we can now safely depend upon in cables?

Mr. Walter F. Wells:—In reply to Mr. Mershon's question, I would say that it is the practice of the New York Company not to make over-voltage tests on cables; and this also applies generally speaking to all electrical apparatus. Apparatus as well as cables thoroughly tested before being installed. A test of a slight over-voltage, say 20 per cent. to 30 per cent., is enough to determine whether the work has been properly done or not.

As to the four faults referred to by Mr. Torchio, which might have been found by an over-voltage test originally, two of them were probably short bends in manholes. As to the other two, I am not well enough acquainted with the records to know which they were. They must have been some of the faults in splices.

Those shown by low insulation test evidently were good in the beginning and gradually deteriorated.

Mr. Mershon:—How about these faults designated as "in splice?"

Mr. Wells:—Those evidently were all right in the beginning and gradually deteriorated, whether due to external injury or not, I cannot say. Several companies operate in the same manholes, and sometimes the cables are roughly handled by employees of other companies or by contractors working on the Rapid Transit Subway excavations.

Mr. Stott:—In reference to the absence of tests on cables, I would say it is the practice of the company with which I am connected to make a 30 minute test of 100 per cent. over-voltage. That is to say, on the 11,000 volt cables which we operate, we would make a 30 minute test at 22,000 volts on the insulation between the three conductors and between the conductors and the ground. We find that a joint which is comparatively poor will stand up as long as 18 minutes and then break down, and in every case where we have broken down cables, with the 30 minute test, the result has been fully justified by what we found in the joints. Incidentally, I can perhaps throw a little light on Mr. Mailloux's question as to the reliability of cables. We have in operation on 11,000 volts, three-phase, over 120 miles of underground cable. Out of that 120 miles we have had only one fault in the cable itself. All the rest were due to inferior work in the joints; and I would say that since they went into operation 20 months ago, we have had a total of four breakdowns while operating. All the rest were taken care of in the over-potential tests. Out of the entire 120 miles there has only been one spot of weak cable. I think that is a very remarkable record and one that shows that 11,000 volts is an absolutely safe voltage. We have the feeling that 11,000 volts is a great deal easier to handle underground than 650 on a grounded return circuit, because you are very liable to get a very large current coming back through the lead covering.

On the grounded system, such as we operate, no matter how much copper you put in to bring back the current to the negative bus-bar, it is almost a physical impossibility to get enough copper in the street to reduce the drop below, say, 10 volts. The lead sheet of a cable 2⅝″ diameter has a resistance of approximately 1/10 of an ohm per thousand feet, so that a length of 500 feet subjected to 10 volts will give you something like 200 amperes in the lead sheath. We found by actual test that the lead sheet of such a cable, 2⅝″ external diameter, and the sheath itself being 9/64th inches thick, would only stand 400 amperes continuously until it reaches 100° C. rise. That of course was too high. I think that a great deal of the underground trouble has been due, not to faults in the insulation but to faults in the lead sheath. That is to say, stray currents from other properties have got back into that lead sheath and melted off the lead in spots where it touches the hanger in the man hole. Of course, that admits moisture, and the insulation gradually deteriorates and breaks down.

Incidentally, I do not think it is worth while considering or discussing rubber-insulated cables at the present time, because the cost of a rubber cable is approximately 100 per cent. greater than that of a paper cable.

We have installed reverse-current relays in our substation feeders, but owing, as I said, to the fall in potential affecting the shunt coils, we found them entirely unreliable. That is to say, in case of short circuit in one feeder, the other feeders will all go out together, owing to the overload current carried by them through the substation to the break in the cable; so that whenever one feeder went up it invariably meant that the entire substation was shut down for a period of from two to five minutes, according to the number of rotaries that were running. Again, there is always a doubt existing in the mind of the operator as to which one of the five or six feeders was in trouble, as all the circuit-breakers went out at the power house, and it was very difficult for them to tell, without testing, which one was in trouble. I do not know how Mr. Wells' people operate in that way, but we found it absolutely impossible to determine which feeder was in trouble, as all the overload breakers went out simultaneously. To get around that, we simply separate the feeders at the substation so that each feeder supplies its own rotary. We have had short circuits on feeders since that change was made and the automatic apparatus took care of it perfectly without any interruption whatever to the service at the power house or substation. In fact, no one knew anything about it until the indicating lamps showed that the oil-switch had gone out. I believe a new device has been gotten up by one of the manufacturing companies which is really not a reverse current relay, but a system they have of causing one relay to lock the others. Suppose there are three or four feeders in multiple—the one which has the short circuit on it will evidently receive the greater amount of current. Therefore its solenoid will move up faster than the others, which are merely carrying the overload. As that one reaches the limiting point it closes a contact which locks all the other feeder relays in that substation. As soon as it breaks it trips its own circuit-breaker; then it releases all the other relays again. It is simply a little solenoid at right angles to the core of the primary solenoid, and it drags over the core so hard that it cannot move vertically. That has been laid out and is going to be installed on the underground division of the Interborough Rapid Transit Company, but I do not think it has been put into actual use up to date.

MR. H., W. FISHER:—I will commence by answering Mr. Mershon's first question.

About two months ago I spent nearly five weeks with the Niagara Falls Power Company conducting experiments to determine the rise of temperature due to different currents on cables laid in ducts. We experimented on different single conductor cables ranging from 3/0 to 1,250,000 c.m., and also on two and three conductor cables. The temperatures of the ducts at different points were determined by means of thermo-couples, consisting of rubber covered iron and German silver wires, all of which had previously been compared with a thermo-couple which we used as a kind of standard and the terminals of which we kept daily at the temperatures of ice and of boiling water. We also used resistance coils which had previously been calibrated to give the variation of resistance with temperature. Our experiments revealed the fact that there was a great deal of difference in the radiating power of different ducts; that the corner ducts radiate best, and the middle and top ducts become the hottest. Some tests made by the Niagara Falls Power Company revealed the fact that the top ducts were the hottest; an explanation of this is that there were openings here and there at points where the terra-cotta ducts were joined together, through which the heated air circulated in an upward direction.

Tests of different numbers of 1,250,000 c. m. cables showed that the rise in temperature of the duct when four cables were employed was 85 per cent. of what it was when eight cables were employed; and when two cables were employed the rise was 74 per cent. of what it was for eight cables.

The Niagara Falls Power Company is in some cases using water circulation in iron pipes to reduce the temperature of the ducts, and by so doing a reduction of 20° Centigrade was obtained in one case.

MR. MERSHON:—What is the maximum temperature that a cable will stand continually without injury to the insulation?

MR. FISHER:—I can say that 100° Centigrade continually applied to a paper cable will eventually deteriorate the paper, making it quite brittle.

I am conducting experiments along this line now to find out the maximum temperature which will not injure paper-covered cables.

With reference to Mr. Mailloux's question as to whether cables sold for a certain voltage could not be subjected to twice that voltage when it is desirable to raise the voltage in the generator plant, I would say that it is hardly fair to subject cables to a working pressure much in excess of what they are designed for. Whether this could be done or not would depend largely on the kind of cable and the voltage at which it was normally designed to work.

MR. MAILLOUX:—What is the highest voltage you have made them for?

MR. FISHER:—Cables are working now at about 22,000 volts.

MR. MAILLOUX:—Are they to be obtained under guarantee for that amount?

MR. FISHER:—Yes. By experience and experiment we are continually learning improved methods of manufacture and dis-covering better insulating compounds, and for some time at least I think we will be able to supply what is likely to be required in the line of high-voltage cables.

MR. MAILLOUX:—You say 22,000 volt cables are commercially obtainable to-day?

MR. FISHER:—Yes.

MR. MAILLOUX:—That is what I wanted to know.

[COMMUNICATED AFTER ADJOURNMENT BY MR. W. L. WATERS.]

ELECTRIC CABLES FOR HIGH-VOLTAGE SERVICE.

I think the question of rubber vs. paper for high-tension cables is a commercial rather than an engineering question. Paper cables are simpler to manufacture, and hence are usually more reliable in practice, but I think there is nothing to choose as regards reliability between well-made rubber and well-made paper cables, provided they are lead covered.

I used to be connected with a firm which has probably had more experience than any other in the manufacture of rubber insulated cables, and we found that the chief points for reliability in rubber cables were good vulcanizing and keeping the rubber from contact with the air. No amount of text-book science will teach a man how to vulcanize a cable; it is an operation that can only be learned by experience. And if the men making the cables have not had this experience, the cables turned out by any firm will in all probability not be very reliable.

The rubber on a cable which is poorly vulcanized becomes rotten after being in service for a certain length of time, and it cracks and crumbles, especially when subjected to mechanical stress. When rubber is exposed to the air for any length of time, the sulphur apparently works out to the surface and oxidizes, forming sulphuric acid. This effect is more pronounced when the insulation is under electric stress on account of the formation of ozone, and is also more marked in a cable which is poorly vulcanized. The result in any case is the same, that the cable breaks down sooner or later.

In rubber cables, as in most other questions regarding the permanence of insulation, the purchaser is more or less at the mercy of the manufacturer, and I think that the cable manufacturer should receive his due share of the credit for a number of the mysterious breakdowns that we hear of on high-tension rubber cables.

DISCUSSION ON " USE OF AUTOMATIC MEANS FOR DISCONNECTING DISABLED APPARATUS."

MR. R. S. KELSCH:—A plant operated by the writer for five years, was equipped with expulsion type fuse blocks using aluminum fuses, on the eight 750 k.w. generators, and the same type of fuse on the eight 5000 volt transmission lines at both the receiving and the generating ends, and gave excellent results.

On one occasion the collector rings for the field leads of one of the generators short-circuited when the eight machines were operating in multiple. The disabled generator was disconnected from the system without the trouble being recorded on the recording voltmeter in the city substation.

On several occasions one or more of the lines were short-circuited by wire thrown on the transmission line, and on each occasion the disabled line was disconnected without interrupting the service. During the past year, relays have been employed and the fuses removed, and we have not had as good results.

Recently a dead short-circuit on one of the secondary circuits protected by a time-limit overload relay set for three seconds caused the potential of the system to fall so low that all power service was interrupted.

Reverse-current relays should be set to operate at five per cent. reverse current. Reverse current should not occur except under abnormal conditions and under these conditions, the apparatus protected by reverse-current relay, should be disconnected instantaneously, and should not have a time element attachment. A reverse-current relav so constructed would operate before the potential lowered sufficiently to make the relay inoperative. The only objection to setting a reverse-current relay to operate at five per cent. is the difficulty in synchronizing. This, however, can be obviated by synchronizing with the incoming generator pressure slightly above the bus pressure and the synchronizer indicating that the speed of the incoming generator is a trifle higher than the general system, which will insure the incoming machine acting as a generator the instant the switch is closed.

Dr. F. A. C. Perrine:—One question which has been touched on by a number of papers in this discussion, but which has not been specifically treated, is that of the proper subdivision of the lines for their protection from interference. The apparatus for line switching and line insulation has been treated for protection against lightning and the subdivision of the circuits has been considered, but it seems necessary to call attention to the fact that we have not, as yet, treated the question of dividing the line up into sections so that in case of accident the interference with the proper maintenance of supply by reason of the use of multiple lines shall not become excessive.

The importance of this was recently called to my attention by some calculations I have been making on a line 350 miles long, for which figures have been requested. If two lines were installed for this transmission, using such a size of copper as the question of economy would best warrant, the regulation, when only one of the two lines was in service, would be too bad for the proper supplv of energy to the service. In consequence it was necessary to consider whether the size of line wire be increased or the line divided up in sections, which would permit cutting out only a short section in case of accident anywhere along the line.

In lines approaching 100 miles in length, the capital invested in each pole line is very considerable and in addition to the loss of energy which must be excessive if but one of the lines is in operation, there is a heavy capital charge during such times which must be carefully considered.

On most long-distance lines there are points of distribution along the line which naturally cut such a line up into sections and if switching stations are installed at these distribution points, permitting the transposition of the circuits, the effect desired can be accomplished but it is not always possible to rely on the fortuitous arrangement of switching stations. With increased length of line, there may be great distance between these switching stations, and furthermore the change-over switches operate under much more serious conditions when the sections they are controlling are long than when they are short.

It is true that up to the present time there has been a general tendency to avoid multiplying switching stations on account of the imperfection of high potential switching apparatus and the increased danger induced will be somewhat above the necessary imperfection of insulation in the switching apparatus itself. Such imperfection, however, is not a necessity and is one of the questions which must be solved in order to obtain satisfactory long distance transmission. This problem solved, the multiplication of switching points is feasible and this implies that with long lines; where two or three duplicate transmission circuits are established, it will become necessary to establish switching sub-stations for no other purpose than the cutting out of sections in the line when repairs become necessary, thus obtaining satisfactory regulation, the efficient employment of the large amount of chemical which is necessarily employed in the transmission for great distances.

Such switching stations have been proposed as frequently as ten miles apart. The ordinary practice is not to install them more frequently than fifty miles apart. It is the writer's opinion that they should not be more distant than twenty-five miles, and their location at fifteen or twenty mile points would be more practical. Handling circuits at this short distance will be easier on the switching apparatus itself. Where switching stations are installed fifty or seventy-five miles apart, the high capacity of the line between switching stations increases the difficulty of switching, but even at the highest voltages, transposition switches can be installed with comparative ease, provided only, as I have already said, their insulation be sufficient to prevent concern for the safety of the circuit from this cause.

In connection with this question comes in the important problem of the use of automatic switching apparatus for such switching, and while the writer believes that the use of automatic switching apparatus be very advisable, at the same time we must recognize that at the present time the main problem of switching has not been so satisfactorily solved as to permit our consideration of automatic apparatus, however desirable it may be.

President Scott:—We have had to-day, according to a little account I have been keeping here, something like 75 contributions to the discussions on the papers which have been presented.

You will notice that the papers which have been presented, eight in number, are all by recognized experts in their several lines of work, and the discussions are from equally well-known men. Our Committee on High-Tension Transmission is to be very highly congratulated on what they have given us, and the response they have obtained.

We are adjourned until half-past nine to-morrow morning.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 21, 1903.

THE FACTORS WHICH AFFECT THE ENERGY LOSSES IN ARMATURE CORES.

J. WALTER ESTERLINE AND C. E. REID.

The investigations which form the basis of this paper have been conducted at the Electrical Laboratory of Purdue University during the past two years. The purpose was primarily to develop an apparatus suitable for rapid yet accurate testing of sheet metal used in armature cores; secondary to this was the study of the effect of certain factors upon the energy losses which occur in the armature cores of generators and motors.

THE APPARATUS.

A general view of the apparatus is given in Fig. 1. The wrought iron field-ring is 14 inches in diameter, 3 inches in width, with an inner diameter of 10⅜ inches. This yoke is provided with five sets of poles, as follows: (1) 2 poles, solid wrought-iron;(2), 4 poles, solid wrought iron; (3), 6 poles, solid wrought iron; (4), 8 poles, solid wrought iron; (5), 2 poles, built of .022 sheet steel. The poles are so dimensioned that 50% of the armature core is covered by each set. The field poles and exciting coils are shown in Fig. 2.

The apparatus was designed so that the specimens for test would be in the form of ordinary armature punchings, and the samples tested consisted of seven cores built up of sheet steel discs .015 inches thick. Fig. 3 is from a photograph of discs from the different cores. The outer diameter of these is six inches, while the inner diameters vary from 2 to 5 inches, in different cores. Four of the specimens tested have a smooth periphery, and three others, with corresponding inner diameters, are slotted. The slots in these cores are 48 in number and 3/16 inches wide by ½ inch deep.

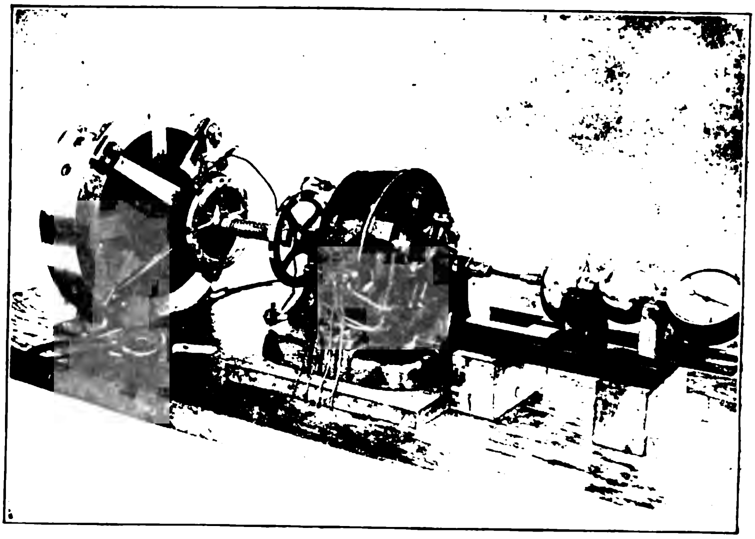


FIG. 1.

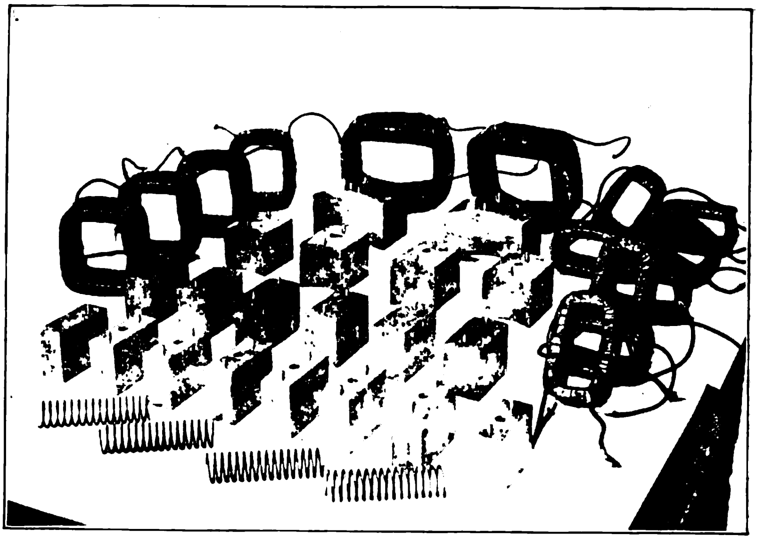


FIG. 2.

To insure a uniform quality of metal in all the cores, the discs were all stamped and then thoroughly shuffled, after which the holes were punched in the different lots. The slots were milled in the cores which were to be toothed, and all the discs were carefully annealed.

The punchings were given a coat of shellac and mounted on hardwood sleeves which fit a heavy steel shaft carried in bearings fastened directly to the field-ring.

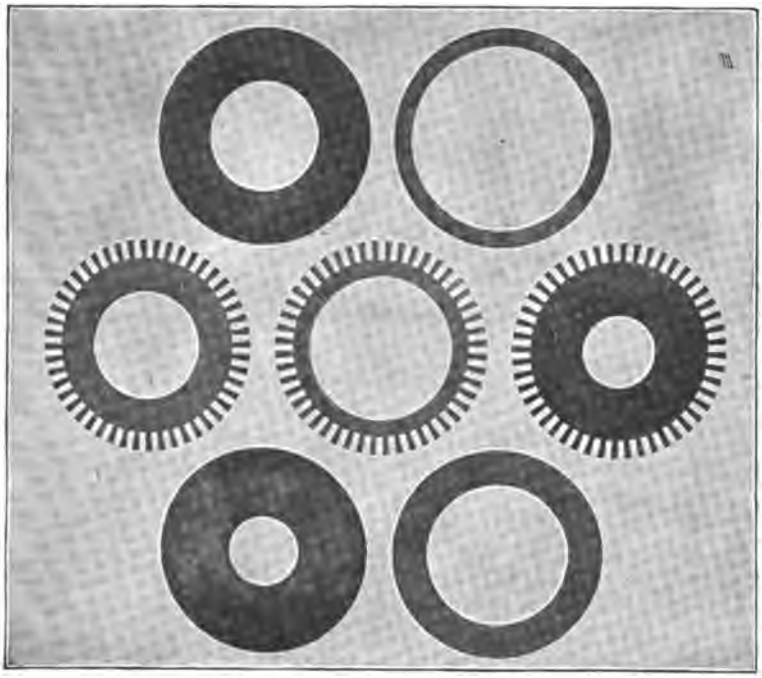


FIG. 3.

In order to insure a uniform density in the air gaps under the different poles, so that there would be no undue increase in the bearing friction when the fields are excited, and to insure an equal distribution of the flux in the core, the poles were bored while clamped in the field ring, the tool being carried on the shaft.

The shaft was driven by a small direct current motor through a modified form of the Goldsborough torsion dynamometer shown in Fig. 4.* The bearings which formed a part of the

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*TRANS. A. I. E. E., 1900.

original type of dynamometer were discarded, one of the wheels was carried on the driving-end of the motor shaft and the driven member fitted to a quill which fits the shaft of the apparatus, permitting the removal of the latter without disturbing the adjustment of the dynamometer spring. The dynamometer was adjusted to the desired degree of sensitiveness by changing the size of spring used.

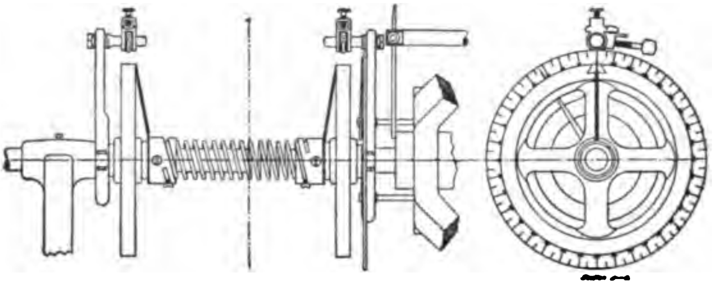


FIG. 4.—Dynamometer Details.

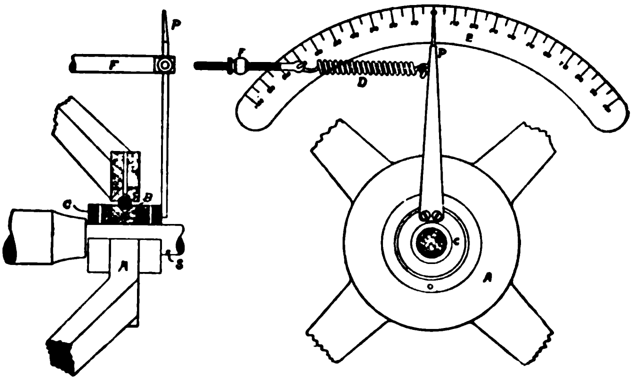


FIG. 5.—Bearing Details.

In order to detect and correct for any change of the bearing friction, should the armature become magnetically unbalanced, or the lubrication of the bearings imperfect, the bearings were made of special design, as shown in Fig. 5. The shaft runs in the phoshpor-bronze bearing C, which, instead of being fastened firmly to the arm A, is mounted in a ball bearing B. When the shaft is rotating, the friction tends to cause the bearing C to rotate with the shaft, as the friction of the ball-bearing was found by test to be negligible in comparison with that of the plain bearing. Instead of allowing C to rotate, it is held by a spring D attached to an arm at P. At the beginning of a run the adjustment at F was made such that the pointer stood at O when the machine was running at the speed at which the test was to be run. Any increase in the friction of the bearings is measured by the movement of P in the direction of rotation, and the reverse for any decrease. The divisions on the scale E represent the number of degrees through which it is necessary to twist the dynamometer spring to produce the given deflection of the spring D, *i.e.*, 10 divisions on the scale E indicate that if the torque necessary to twist the dynamometer spring through 10 degrees be applied to the spring D, the pointer will indicate 10. Such a scale was calibrated for each of the two bearings for each of the dynamometer springs used, by clamping the bearing C to the shaft, and marking the position of P corresponding to the different angles through which the dynamometer spring was twisted in order to produce the deflection of D.

The driving-motor was operated separately-excited, and variable speed was obtained by changing the impressed e.m.f. of the armature. The speed was indicated by a Buss-Sombart tachometer attached to the armature shaft of the motor.

PURPOSE AND METHOD OF TESTS.

The energy losses which attend the rotation of an armature core in the magnetic field consist of the bearing-friction and windage, hysteretic and eddy current loss in the core in the case of smooth cores, to which is added an eddy current loss in the pole faces when the cores are toothed.

As indicated in the following diagram, the hysteretic losses may be said to depend upon the quality of the iron, the frequency of the flux reversals and the maximum density reached during a cycle. The frequency is a function of the number of poles and the speed. The maximum magnetic density is dependent upon a number of conditions, and is usually different in different parts of the core at the same instant. The distribution of the magnetic flux through the core depends mainly upon the depth of the core, the number and pitch of the poles and the dimensions of the tooth and slot. The greater the radial depth of the core, the greater the difference between the maximum and minimum densities within the core, for a given average density, and as the depth of the core becomes less the distribution of the flux becomes more and more uniform. The cores of different internal diameters were tested to determine the effect of the variation in the flux distribution upon the core loss. The frequency and flux distribution both being dependent upon the number of poles in a machine, these cores were tested under different numbers of poles also.

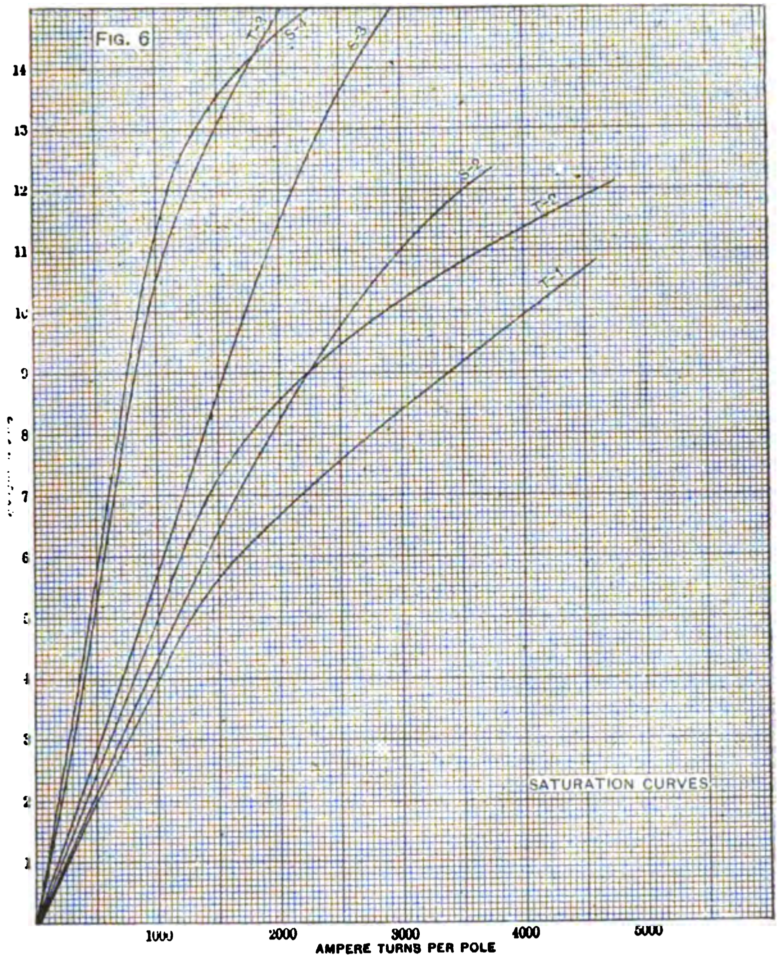
When an armature core is slotted, the magnetic density in the teeth is greatly increased for a given air gap or core density, and the presence of teeth on the core is attended by an eddy current loss in the poles. The latter may be greatly reduced by laminating the poles, so that a comparison between tests of a toothed core under solid and laminated cores should indicate to what extent this loss in the pole faces may be reduced. The increase in the energy expended due to the higher densities in the teeth may be shown by comparing tests of smooth and toothed cores under well laminated poles.

- Total
  - Hysteretic loss.
    - Quality of iron.
    - Frequency.
      - No. of poles.
      - Rev. per second.
    - Max. Density.
      - Air gap flux per pole.
      - Cross section of core.
      - Distribution of Flux.
        - Depth of core.
        - No. of poles.
        - Dimensions of tooth and slot.
  - Eddy Currents
    - Core
      - Frequency.
      - Lamination.
      - Density.
    - Poles
      - Density.
      - Size of teeth and slots.
      - Air gap length.
      - Degree of lamination.

To make a core, enough discs of one kind were selected to give a gross length of 3 inches. These were weighed, given a coat of shellac and assembled. Before placing the core within the field an exploring coil was wound about the face of one of the poles and another wound so as to embrace the total flux passing through one section of the core. After placing the sample in the apparatus, a saturation curve was taken by means of a ballistic galvanometer in connection with the exploring coils just mentioned. These curves (Fig. 6) show the relation between ampere-turns per pole and average magnetic density in the core.

The field poles were next thoroughly demagnetized by an alternating current. On starting the motor, the dynamometer reading indicates the bearing friction and windage, the springs which hold the bearings were adjusted so that the reading of the pointers P, was zero.

FIG. 6



The speed being adjusted to give a desired frequency, it was held constant, and the exciting current varied stepwise, readings of current in the fields, dynamometer and scale for bearing friction, being taken simultaneously for each value of current. When maximum current was reached, the fields were again demagnetized, the speed changed to give the next desired frequency, the bearing springs adjusted and the operation of varying the current repeated. Each core was tested in this manner under five sets of poles, at five different frequencies and varying magnetic densities, making 225 complete tests.

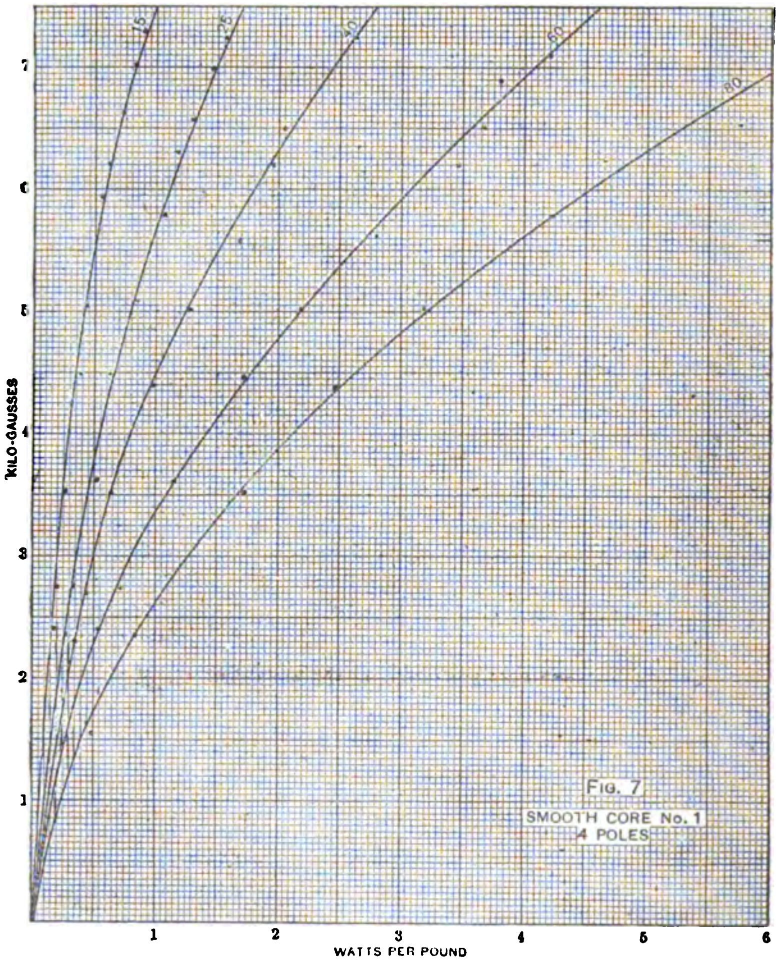


FIG. 7
SMOOTH CORE No. 1
4 POLES

When the fields are excited, the power required to drive the core consists of the friction and windage and iron losses. The difference between the dynamometer reading for any current, and the friction reading, is the iron loss. If the pointers attached to the bearings indicate any change in the friction, the amount so indicated can be subtracted from or added to the original friction reading, depending upon whether the friction has decreased or increased, since the scales E are graduated in degrees of the dynamometer spring. From the corrected dynamometer readings the watts core-loss in watts was determined, which divided by the weight of the core gives the watts per pound. Referring to the saturation curve, the densities in the core for

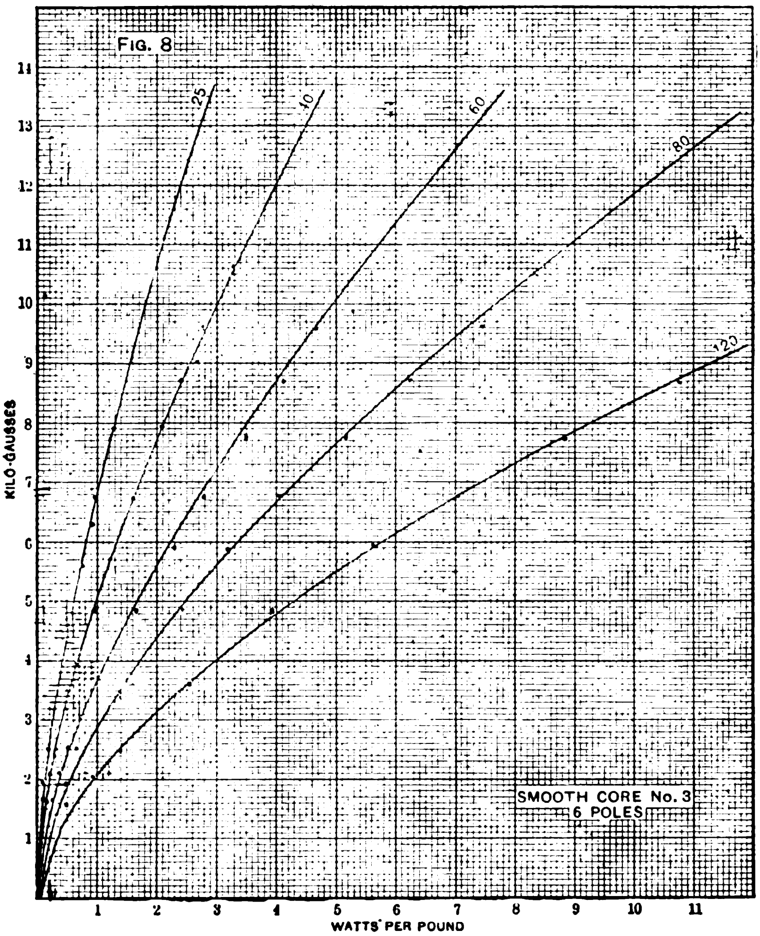


FIG. 8

the different values of ampere-turns per pole are found, and curves plotted for each frequency, average density as ordinates, watts per pound abscissæ. The original curves from 2 of the 35 tests are shown in Figs. 7 and 8. The current in the exciting coils was taken from a storage battery and measured by a

Weston laboratory standard ammeter. The dynamometer was frequently calibrated, and gave the same result each time. The centering of the cores in the bore of the poles was so successfully accomplished, that there was very little increase in the friction due to magnetic pull. So sensitive, however, were the ball bearing attachments, that the increase of friction due to a drop of cold oil in one of the bearings was readily shown by the pointer.

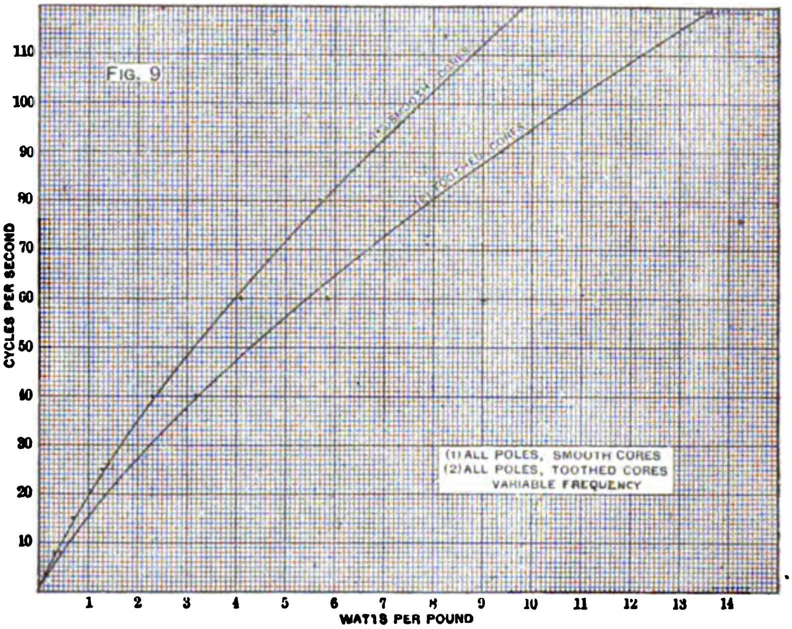


FIG. 9

RESULTS.

To illustrate the relation between the core loss and any one of the four variables—frequency, magnetic density, number of poles and depth of core—curves have been drawn from data derived from the 35 original curves. In order that the results should be representative, the three variable factors not under consideration were eliminated by averaging all of the tests, for each value of the variable under consideration. For example, Curve No. 1, Fig. 9, exhibits the relation between the frequency in cycles per second and core loss in watts per pound, for all the cores having smooth periphery, under sets of 2, 4, 6 and 8 poles, and at magnetic densities ranging from 2,000 to 14,000 gausses, for each value of frequency.

Curve No. 2, in the same figure, shows a similar relation for all of the toothed cores. The curve for the cores having teeth shows considerably higher losses, due to the energy loss in the pole faces and the increased hysteresis loss resulting from the high magnetic density in the teeth of the core.

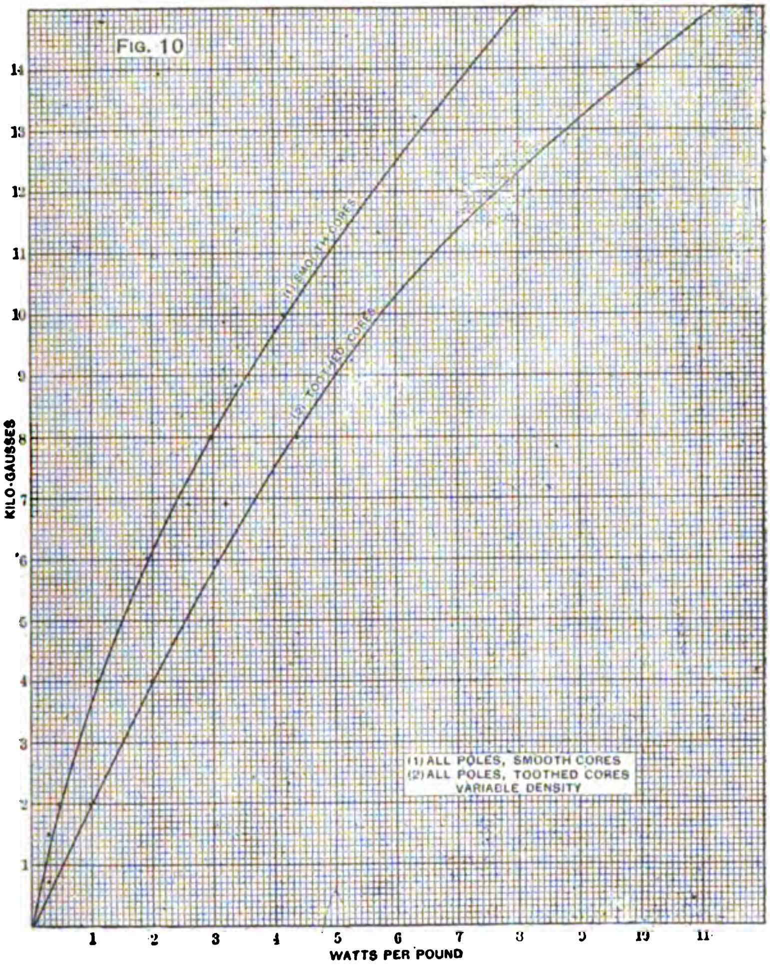


Fig. 10

Curve No. 1, Fig. 10, gives the relative values of the core loss and maximum average magnetic density for all of the smooth core at frequencies ranging from 7.5 to 120 cycles per second. Curve No. 2 shows a similar relation for the toothed cores.

In studying the effect of variable numbers of poles and depth

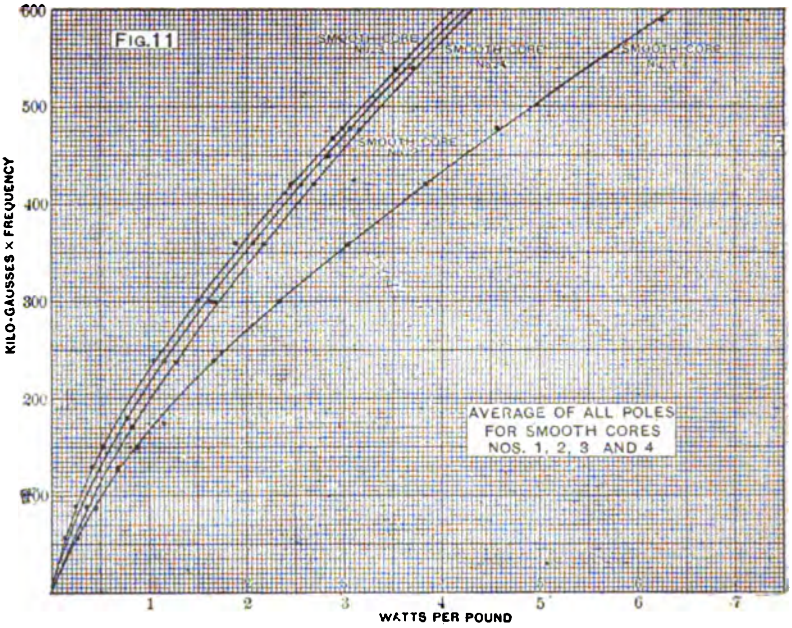


Fig. 11

AVERAGE OF ALL POLES
FOR SMOOTH CORES
NOS. 1, 2, 3 AND 4

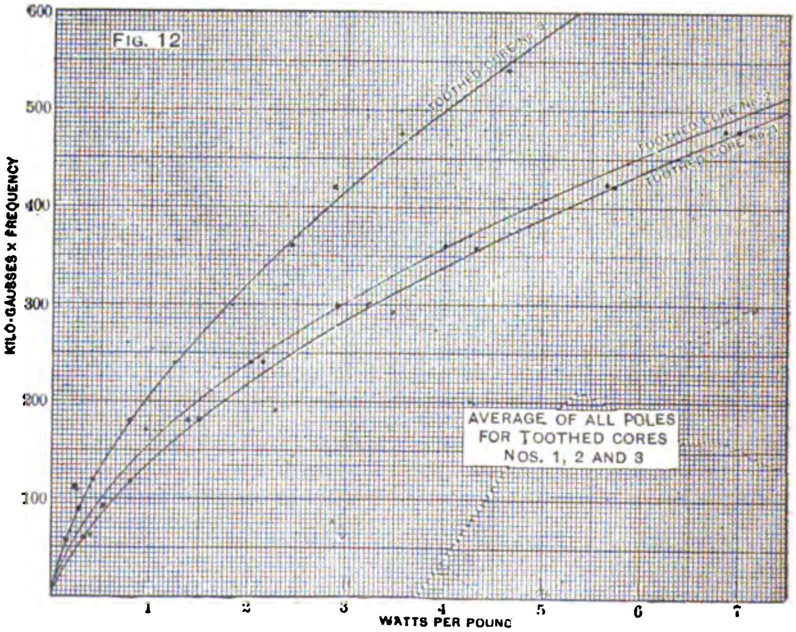


Fig. 12

AVERAGE OF ALL POLES
FOR TOOTHED CORES
NOS. 1, 2 AND 3

of core, the product of the frequency and magnetic density was considered as a single variable. As shown in Fig. 11, the relatively shallow cores, in which the magnetic density is more nearly uniform, have the lowest values of core-loss for the same average magnetic density and frequency. The same is true for the toothed cores, as shown in Fig. 12. The lines of force in passing from pole to pole through the core, seek the path of least reluctance, and in so doing increase the density in the outer portions of the core. In Fig. 11, core No. 1 has a radial depth of 2 inches, No. 2, 1.5 inches, No. 3, 1 inch, No. 4, .5 inch. Of the toothed cores, the results from which are given in Fig. 12, core No. 1 has a depth below the teeth of 1.5 inches, No. 2, 1 inch, and No. 3, .5 inch.

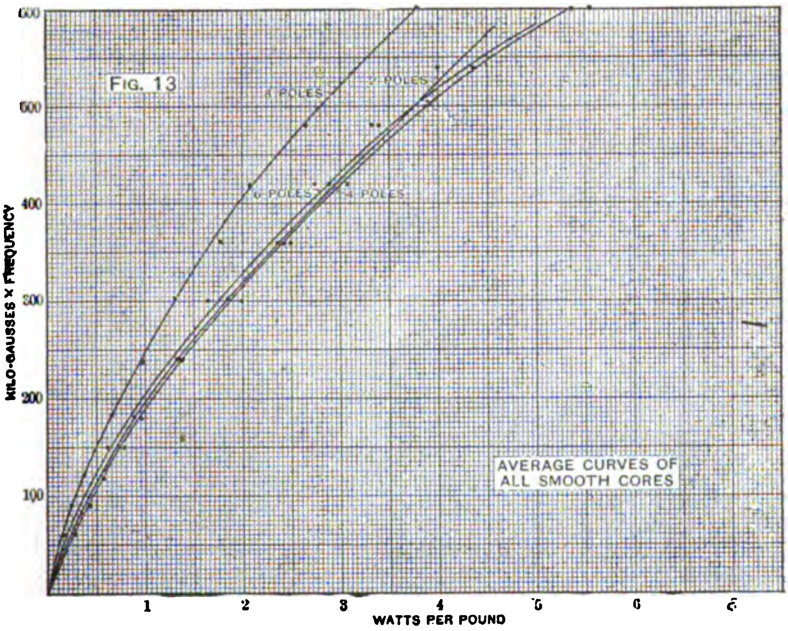


FIG. 13

Fig. 13 would indicate that there is practically little change in the core loss for different numbers of poles, for the same magnetic density and frequency, so far as the smooth cores are concerned. The curve for 8 poles differs from the other three on the same sheet, more probably due to the fact that it was impossible to obtain as high magnetic densities with these poles as with the others, but the frequencies obtained were of course somewhat

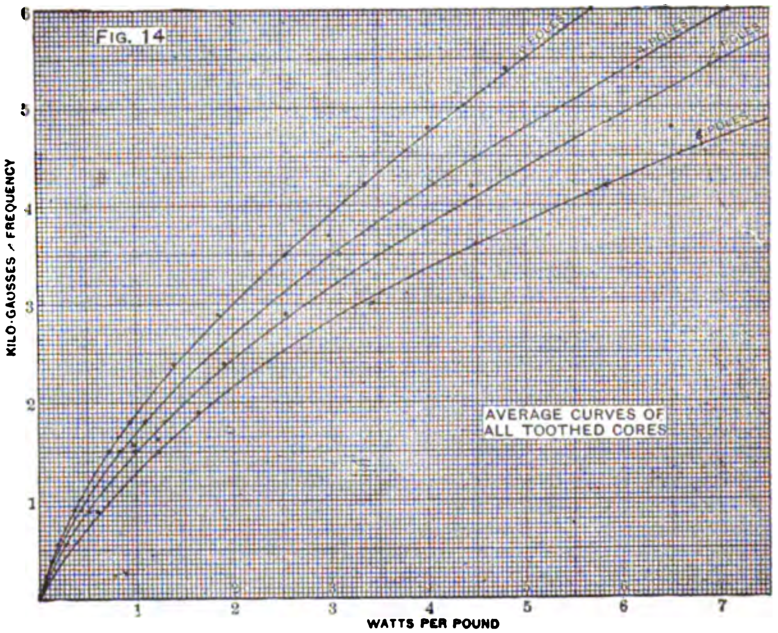

KILO-GAUSSES ÷ FREQUENCY
6
5
4
3
2
1
POLES
POLES
POLES
4 POLES
AVERAGE CURVES OF
ALL TOOTHED CORES
1
2
3
4
5
6
7
WATTS PER POUND

FIG. 14

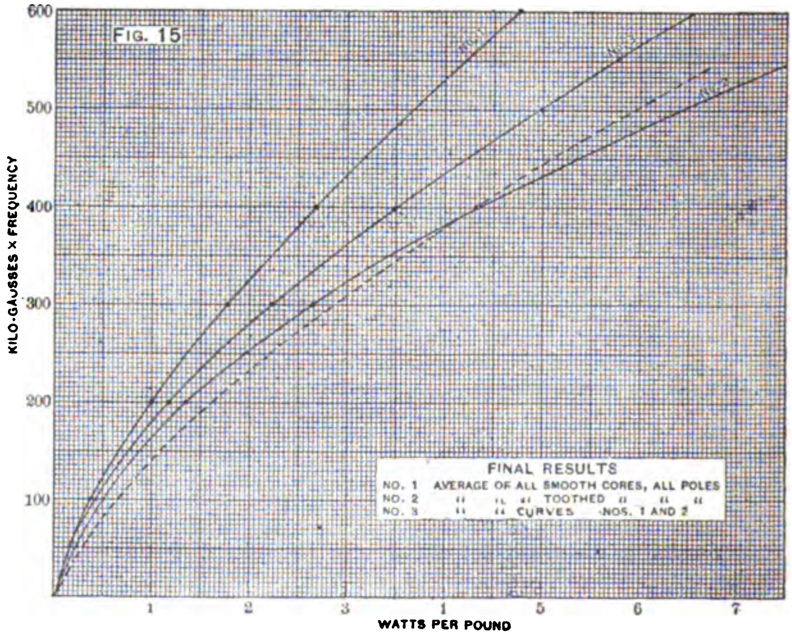

KILO-GAUSSES × FREQUENCY
600
500
400
300
200
100
NO. 1
NO. 2
NO. 3
FINAL RESULTS
NO. 1 AVERAGE OF ALL SMOOTH CORES, ALL POLES
NO. 2 " " " TOOTHED " " "
NO. 3 " " CURVES NOS. 1 AND 2
1
2
3
4
5
6
7
WATTS PER POUND

FIG. 15

higher. However, in the case of the toothed cores, as shown in Fig. 14, there is considerable variation in the core loss for different sets of poles, at the same frequency and density.

In Fig. 15 curve No. 1 is the average of the four curves shown in Fig. 13, and therefore is a summation of all data taken on the cores having smooth periphery. Curve No. 2 in the same figure is a similar deduction from all the data on the slotted cores. The increase in the loss of energy due to the slotting of the core is plainly set out, as shown by the difference of the values of the abscissæ of the curves 1 and 2. Curve No. 3 is a final average of the results from all the smooth and all the toothed cores and is the result of some 12,000 observations.

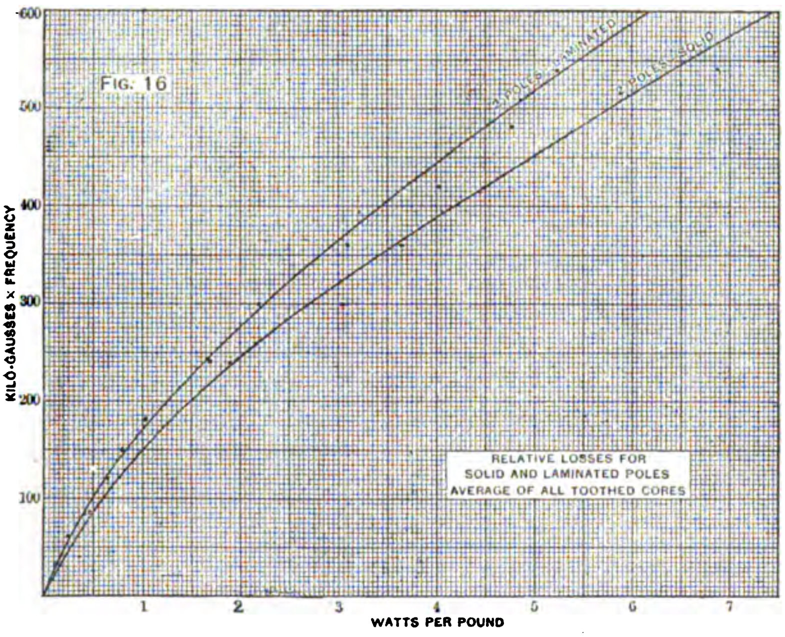


FIG. 16

Curve No. 1, Fig. 16, is the mean result of all the toothed cores tested under a pair of laminated poles, while Curve No. 2 in the same figure is the result of tests of the same cores under a pair of solid poles; the difference in the abscissæ of these two curves denoting the reduction of the eddy current loss in the poles due to lamination of the same. In building up the laminated poles, no effort was made to produce a laminated pole in any way superior to those obtained in commercial practice. After the poles were built up, they were faced inside and out, in the lathe; and the tests conducted on the poles just as they came from the lathe, no attempt being made to remove the effects of the tool in forcing the plates together.

It will be noted in curve No. 1, Fig. 16, the toothed cores and laminated poles check fairly closely with curve No. 3 of Fig. 15, which is the average of the smooth and toothed cores under solid poles, and also that the difference between curve 2 and 3, Fig. 15, is very nearly equal to the difference between the curves in Fig. 16. This being the case, we should expect curve No. 1, Fig. 15, to be representative for smooth cores under either solid or laminated poles; curve No. 3 for toothed cores, with laminated poles and curve No. 2 for toothed cores and solid poles. The broken curve (Fig. 15), is from the core loss tests of a large number of machines having, in the majority of cases, toothed cores and solid cast poles. Since these machines were built and tested by the manufacturing company which furnished the material for the cores which were the subject of these investigations, the last conclusion at least seems justifiable.

In conclusion the authors desire to express their obligations to Messrs. A. E. Wood and C. A. Davis, of the graduating class of 1902, for much assistance in preparing the apparatus and samples; to Messrs. R. E. Clisby, A. W. McHenry and J. W. Skinkle, class of 1903, Purdue University, for painstaking efforts in making the observations and calculating the results; also to Mr. A. L. Hadley for much valuable assistance.

DISCUSSION.

PROFESSOR ESTERLINE:—I might also call attention to the fact, which is not mentioned in the paper, that for each smooth core which was tested, there was a toothed core, the depth below the teeth corresponding exactly with the radial depth of the smooth core, so that the results from smooth and toothed cores were readily comparable.

PROFESSOR GOLDSBOROUGH:—Professor Esterline in his paper has given us only a small part of the results which he obtained in the course of the experiments, and I think that by reference to his curves we will all agree that some of them represent so many variables that it is somewhat difficult for us without some study and thought to appreciate exactly what they mean. On the other hand, after they have been analyzed they bring to us very much more definite information regarding certain points bearing upon the matter of losses in armature cores than we have ever before had. If you will notice, for instance in Fig. 14, we have a set of curves plotted with watts lost per pound as abscissas, and the product of the flux-density and frequency as ordinates. You will notice that the curve for eight poles falls below the other curves. In other words, we have the curve for two poles below that for four poles, and the curve for four poles below that for six poles. When it comes to eight poles the curve drops down below all the other curves. Now, it must be remembered that these poles are referred to the *same* field ring and the *same* armature cores; that is, at first two poles were used; then four poles were placed in the field rings; then these were removed and six poles were put in the same field ring and finally eight poles were put in. In each case the *same per cent. of the surface of the armature was covered by the poles.* The eight-pole curve falls low owing to the fact that there is saturation in the armature core. For instance, take this to be the armature core (see Fig. E). Here we have the field ring common for all of the cores (indicating on blackboard), and with the eight-pole machine we have the poles making angles of 45° with one another. Now, the densities, if I understand rightly, are taken in the neutral plane (indicating); that is, the density values represent the average densities across the core between the pole tips. We have, of course, a flow of flux from one pole over to the next one, and we get a certain point near the surface of the core where the flux is highly concentrated. As a general thing you will find that the iron at the surface of the core is very much more densely permeated with flux than that at the inner side. In some experiments I have made I found as many as 14,000 lines at the top and only 2,000 lines at the bottom. This is something that we frequently lose sight of—that there is so great a variation in the density between the inner and the outer edges of the laminas.

In the case of the two-pole machine tested we get a greater variation in the core-flux distribution than we do in the case of the four-pole machine, the density there probably being greatest near the *inner edges* of the laminas, owing to the small per cent. of the armature surface covered by the poles and to the fact that the poles are diametrically opposite one another with relatively low air-gap densities, as compared with the core densities between the poles. The six-pole machine gives still less variation; that is, we come to a point where the distance between the pole corners and the air-gap density is such that we get a fairly uniform distribution across the core. When we pass to the eight poles another condition arises.

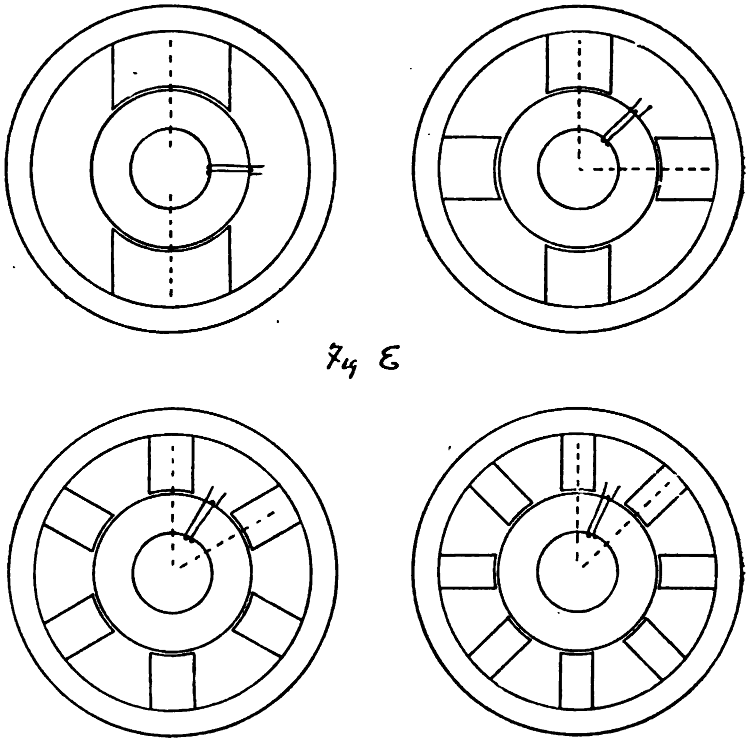


Fig 8

You will see, with the same amount of flux passing between poles, we get a relatively small density in the air-gap of the two-pole machine, by comparison with the others. When we increase the number to four poles the density in the air-gap gets higher. With six poles the density in the air-gap gets still higher. When we come to eight poles the density in the air-gap gets very high, and the maximum loss instead of occurring in any section between the poles, now occurs in the iron immediately beneath the poles. In other words, for the eight-pole curve we have the greatest hysteresis loss occurring right underneath the pole tips, owing to the fact that saturation of the iron occurs immediately below the pole tips. In passing, then, from a two-pole curve up to six and back again to eight, we have passed through a cycle; a cycle in which we first have the greatest loss at points near the bottom of the core and between the two poles, and finally have the greatest loss at the surface of the core under the pole tips. These are matters in design which we do not usually have in mind, for the reason that as a general thing the iron loss in the armature is calculated entirely on the basis of the average density which occurs in the core at a point midway between the pole tips.

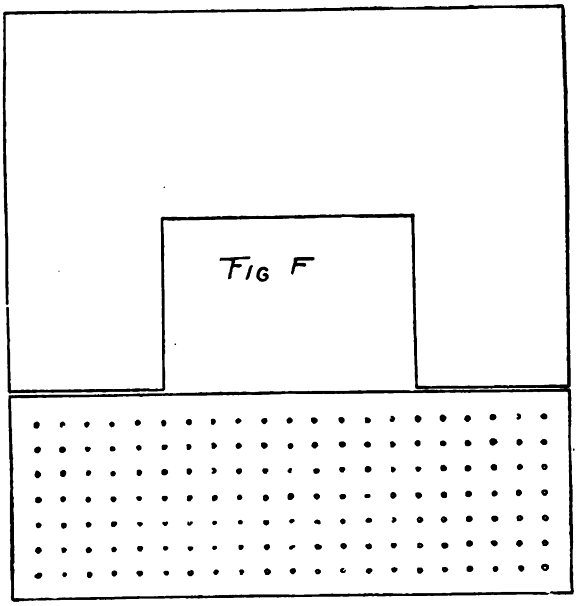


FIG F

Mr. Henry Pickler:—I think we would all be very much pleased if Professor Goldsborough would explain to us by which method he found that on the top of the armature core the density was 14,000 and on the bottom 2,000.

Professor Goldsborough:—That was determined in this way—take a case, for instance, in which we have two poles, as in Fig. F, with the armature core beneath. We took the core and simply bored holes all the way through it, in regular order, as indicated, parallel to the armature shaft. Then by means of exploring coils wound through the holes, and a galvanometer, we obtained readings proportional to the flux-density in different parts of the core by breaking the field circuit. These results have all been brought out in a paper which I had the pleasure of reading before the INSTITUTE at the Boston Meeting, two or three years ago.

PRESIDENT SCOTT:—In the diagram which you first used in the two-pole machine, you showed the difference between the outside and the inside as 14,000 to 2,000. That would not apply in a two-pole, but rather in a many pole machine. A difference so great as that would hardly come in the first figure which you showed here.

PROFESSOR GOLDSBOROUGH:—That depends upon the design of the two-pole machine and especially upon the per cent. of the armature surface that is covered by the poles; these effects are much more pronounced where 80 per cent. of the armature is covered than where only 50 per cent. is covered.

PROFESSOR FRANKLIN:—I would like to call attention to a point in connection with the last statement made by Professor Goldsborough. The *distribution* (sectional) of flux in the iron parts of a dynamo cannot be determined with any accuracy at all by calculations based on the assumption that the pole faces are equi-potential surfaces (magnetically).

Non-uniform sectional distributions of flux are determined by magnetomotive forces which are of the same order of magnitude as the actual variations from constant potential (magnetic) over the pole faces. To ignore these differences is therefore to ignore, it may be, the whole of the cause which leads to non-uniform distribution.

To assume that the surface of a mass of iron under the influence of magnetizing forces is a surface of equi-potential (magnetic) is the same thing as assuming that the reluctivity of the iron is zero, and under this assumption flux distribution in the iron is absolutely indeterminate.

PROFESSOR ESTERLINE:—A number of tests made using the ballistic galvanometer and exploring coil show a very uniform distribution of the air-gap flux, with a small per cent. of fringing at the pole corners.

PROFESSOR GOLDSBOROUGH:—In connection with that I would say that in the discussion which we are having this morning, I did not start out to enter into an ultimate analysis of this problem; but to substantiate my first statement I would like to say that we have found it possible to determine with an accuracy which is greater than experimental accuracy; that is, we can calculate more closely than we can get it experimentally, what the actual density is at each point of the surface of the armature, making full allowance for fringing and the variations in permeability of the iron. Now, further than this, to carry the matter to an ultimate analysis, we have taken into consideration the variations that occur in the reluctance of the iron in the body of the armature core due to variations in flux density; and in addition we have superimposed the armature reaction on top of all the other reactions, and by a method of vectors, we have found exactly the number of lines of force threading the air-gap and the armature core at all loads. The analysis shows that the core loss increases as the load comes on, owing to the fact that the points of maximum density are changed by the armature reaction.

MR. LEONARD WILSON:—I think that all designing engineers will feel very grateful to the authors of this paper for the large amount of experimental work which they have classified in this manner, and will give it the careful study it deserves. What the designing engineer really wants is some method of rapidly and accurately calculating the core loss in armatures, and to do that he wants some method of calculating the loss in each part of the core that is, the loss due to hysteresis and eddies in the core itself, and in the teeth, and the loss that is due to eddies in the pole pieces and in the conductors, etc.; and, having obtained methods for calculating these details, then, by actual tests, he wants to obtain some correcting factor which will make the result approximately correct for the generator as a whole. These curves, as they stand, do not enable one, without analysis, to see exactly what the results are. For instance, the curves of watts per pound and density are usually very interesting, but to assimilate them it is necessary (and it would be interesting) to know what is the approximate equation for those curves. I think for that purpose it would be very useful to plot the results on log. paper, by which means one could see at a glance approximately what the order of a curve was, that is to say, the nearest index for each part of the curve. In testing a number of direct current generators, for core loss it was found that the curve connecting core loss and total magnetic flux was of a very high order in the region of the normal working flux. That is to say, in a number of machines the core loss—which includes all open circuit electrical losses due to the rotation of the armature—will vary as perhaps the 5th or even the 8th power of the density—perhaps an average figure is the 4th power of the density, in the region of normal density. At low densities the index is quite different. I do not know that this paper gives any particulars of the loss in the teeth at high densities. I have not had time to look it through. But it seems to me that one reason for the very rapid variation of tooth loss with the density is that as the teeth get saturated there is a large amount of leakage into the slot, and consequently increased eddies in the conductor, and at normal tooth density the eddy current loss in the conductors, such as it is, increases with the magnetizing force in the teeth; that is to say, increases with the H^2 instead of B^2, and when you are working just at the bend of the saturation curve, the H^2 varies very rapidly, varies perhaps as the 10th or higher power of the density, just for that part of the curve; and that probably accounts for the high order of the curves of density and watts per pound.

MR. MAILLOUX:—I think, Mr. President, I can partly answer the question put by the last speaker in reference to an equation to express these curves. One can see at a glance that these curves can be approximately expressed by an $X\,M$ function.

That is, the equation probably would be $y = b x^n$. There is no constant, because the curves all start from zero; consequently, the equation takes the simplest form. Doubtless it will be found that n is less than unity because the curve has a close analogy to the magnetization curve. The magnetization curve when it is plotted, has an empirical equation of the form $y = a + b x^n$, with an exponent which varies between .1 and .2. It is probable that in this case the exponent would vary with the different curves somewhere between 0.5 and a few tenths. It is a very easy matter to determine the constants, and if I had thought of it I would have worked them out. In a very few minutes one can take two or three points of these curves and work out the constants, that is to say, the coefficient b, which affects the scale of ordinates, and the exponent n which affects the curvature.

Doctor Kennelly:—Owing to the way in which these curves are plotted, bending down instead of up, which I think may be a matter of custom—

Mr. Mailloux:—I was going to refer to that. If you turn the paper horizontally, then in that case you would still have an equation of exactly the same mathematical type, which is a parabola, but the exponent now has a value greater than unity.

Mr. Henry Pickler:—In connection with what Mr. Wilson said, I would like to ask Professor Esterline whether he tried to separate the hysteresis and the eddy loss in the armature, and what is the law that he found?

Professor Esterline:—In reply I would say, that no effort was made to separate the hysteretic and the eddy current losses. The work of getting experimental results ran up very close to the time at which the paper had to be presented, and there was no time to go into those details. It is my hope to carry out the work further at some future time.

President Scott:—This paper (referring to Esterline paper) is in one sense similar to those which were presented yesterday.

As Mr. Wilson brought out, this is not a simple question, but a very complex one. I noted yesterday when we were discussing the problem of lightning protection that some of our Western friends seemed a little skeptical when it was endeavored to express the subject in formulas on the blackboard; and in the present case, if some workman files his armature or bolts it together a little carelessly, these curves may be changed from the x^nth order to some order entirely different. A workman in the shop can shift these curves faster than the investigator can measure them.

Mr. Mailloux:—I shall be very glad if the author of the paper will communicate to me the data relating to the curves, or let me have the curves in larger form to calculate the constants and give, later, in a written communication, for the Transactions, the equation which will approximately represent every one of those curves.

Professor Esterline:—I shall be very glad to do so, considering that there are 225 such curves.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 2d, 1903.

CENTRAL STATION ECONOMIES.

BY W. E. GOLDSBOROUGH AND P. E. FANSLER.

As an example of the most approved modern practice, we have in the State of Indiana one of the finest and most interesting railway plants that has ever been installed. The lines of the Union Traction Company of Indiana traverse six counties of the State—Delaware, Grant, Hancock, Henry, Madison and Marion—and serve a population of 350,000 people. With its 163 miles of track, it forms the largest system in the world operated by one central power house.

It is fair to say that a comprehensive test of this system furnishes much data of interest and value, in view of the prominence which interurban systems have assumed in the industrial movements of to-day. The present paper deals with an important phase of an economic investigation undertaken during the Spring of 1902 which included every element that enters into the system. As a matter of convenience, when the problem of making a commercial efficiency test of the entire system was undertaken, the work was divided into 5 distinct divisions. These were in turn apportioned among 10 seniors of the School of Electrical Engineering of Purdue University, Lafayette, Indiana, who arranged and supervised the work under the immediate direction of the authors.

The present paper deals with a test made to determine the economies of the main power station. Messrs. Stein, Wilson, Reed and Gregg are responsible for the accuracy of the records made, upon which the conclusions herein contained are based.

The main power station is located in North Anderson, adjacent to the interurban line. It occupies a handsome building of natural-gas burned brick with a foundation of Greensburg stone, 117 feet × 165 feet; the boiler room 70 feet × 160 feet, 9 inches, and the engine and generator room 70 feet × 160 feet 9 inches inside, with a height of 35 feet in the boiler room and of 30 feet in the engine room from the floor to the roof trusses. A 10 foot basement gives room for the coal and ash-conveyor under the boiler room and for the static transformers and storage battery under the engine room.

THE BOILER ROOM.

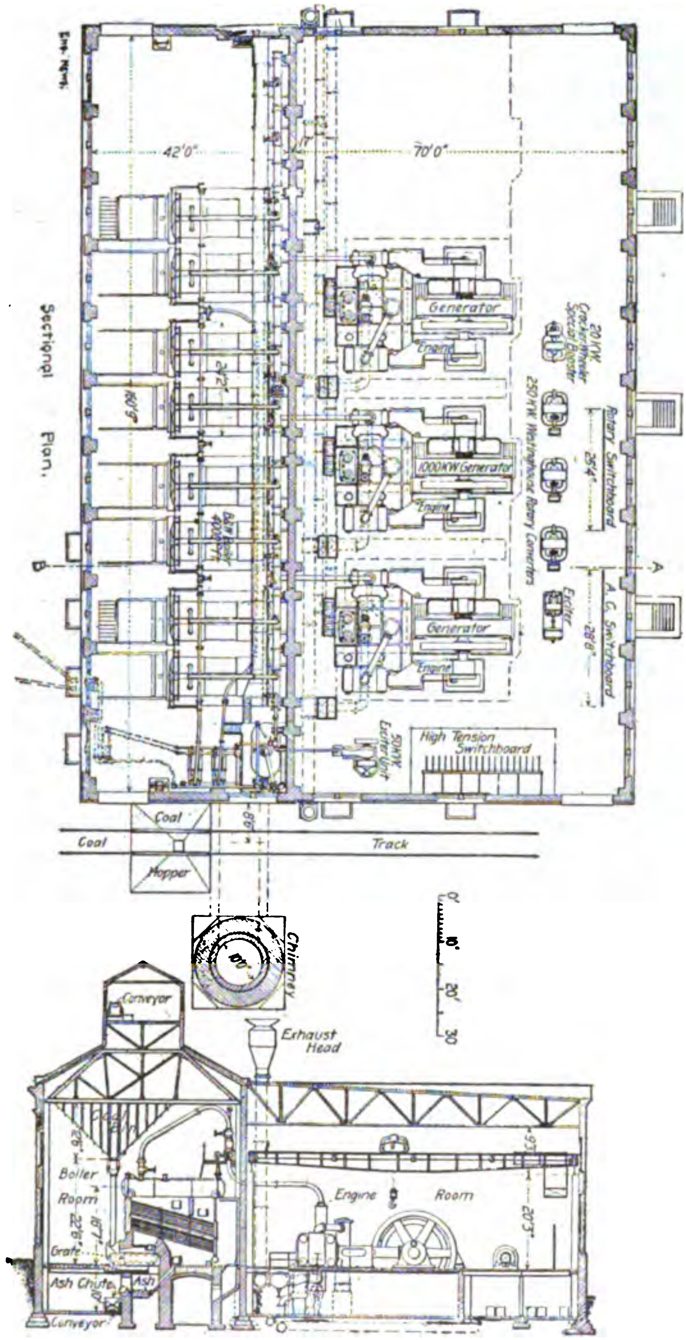
The boiler room is provided with eight Babcock & Wilcox water tube boilers, rated at 400 h.p. each, the principal dimensions of which are:

Number of tubes, 102.
Arrangements, 16 wide and 12 high.
Size of tubes, 4″ diameter.
Two drum, 3′ diam., 16′ long.
O.H. steel, tensile strength, 56,000 lbs.
Steam pressure (rated), 160 lbs.

A large brick chimney, 200 feet high, inside diam. of 10 feet, is located just south of the boiler room, and is connected to the furnaces by means of a tunnel.

The furnaces are served with fuel by Babcock & Wilcox chain grate stokers under each boiler, ample provision being made for handling the coal as follows.

Loaded cars of coal are brought to the side of the station, where a large steel hopper is constructed under the track. The coal is dumped from the cars and passes through the hopper into the coal-crusher located in the basement under the boiler room. After the coal is crushed into pieces about the size of a walnut, it falls into conveyor buckets and is carried to the top of the building and dumped automatically into large steel bins, there being one for each boiler. From these bins hang long spouts for carrying the coal from them to the hoppers of the stokers, the flow of coal being regulated by a sort of damper at the top of each spout. The grates are moved by a separate engine, as is also the conveyor. As the grates move under the boilers, coal is fed from the stoker hoppers where the amount is regulated by means of a striker. The coal is burned on this grate until it reaches the back part of the furnace, when the refuse, such as ash, etc., falls into a pit from which it is drawn



Cross Section A - B.

Central Station at North Anderson, Indiana.

into the same conveyor buckets which carry the coal. The ash is elevated to the top of the building and deposited in a special bin, where it is allowed to cool until such time as its disposal is provided for. It is then loaded into gondola cars and hauled away.

FEED WATER.

The feed water for the boilers is drawn from two deep wells located under the boiler room by means of two deep well pumps. It is raised into a large tank near the station, from which it flows by gravity into a large open heater, where it receives heat from the exhaust of all the auxiliary engines, including the air pumps. From the heater the water is forced through a 6" feed water main by a powerful pump of which there is a duplicate for emergencies. Feed water can be delivered to any or all boilers at the will of the fireman. The water main is located on top of the boilers and so arranged that either pump may be used at any time.

A Dean double acting fire pump is located in the boiler room basement, and is used in cleaning the boilers and in case of fire.

ENGINE ROOM.

There are at present in the engine room three cross-compound Corliss automatic cut-off condensing engines, with a maximum capacity of 2,000 horse-power each, and space for a fourth unit of the same size. These engines are built under a guarantee of less than one per cent. speed variation from no load to full load, with an instantaneous variation not greater than two per cent. in any case. The economy guarantee is that the maximum steam consumption of engine, jackets, air-pump and reheating coils, when under normal steam and vacuum conditions, shall not exceed on an average the equivalent of 14½ pounds of dry steam per indicated horse-power per hour, when the engine and pump under a constant load are together indicating 1,500 horse-power.

The general dimensions of the main engines are: Diameter of cylinders, 26 and 50 inches; length of stroke, 48 inches; speed, 100 revolutions per minute; diameter of balance fly wheel 18 feet; weight, 120,000 pounds; diameter of shaft at middle, 24 inches; dimensions of main bearings, 22 by 58 inches; crank-pin, 8½ by 8½ inches; cross-head pin 7 by 8½ inches; length of connecting rod, center to center, 12 feet. An improved Rites inertia type governor gives a cut-off variable from zero to three-fourths stroke.

Connected to the low pressure cylinders of the engines are jet condensers, the condensed steam and condensing water from which is allowed to escape into a private sewer. However, special connections are made at all joints and at the separators in order that the water in the steam pipes may be drained into the Holly system and returned to the boilers to be evaporated.

The engines may be run non-condensing if it is so desired, and for this purpose large exhaust pipes are provided to carry off the exhaust steam.

Direct connected to each of the three engines is a 1,000 k.w. three-phase generator with rotating fields, separately excited, and designed for 100 revolutions per minute. With 32 poles this gives 1,600 cycles per minute. Each generator has a normal capacity of 1,600 amperes in each of the three phases, the full load voltage being 400. Three means are provided for the field excitation: (1) A 50 k.w. direct current generator, direct connected to a three-phase induction motor; (2) a 50 k.w. direct current generator, giving 125 volts, direct connected to a high speed Ball engine; (3) the storage battery is tapped for 125 volts, to be used in an emergency.

This plant also contains a substation consisting of a storage battery, a booster, three rotaries and a switchboard. This substation equipment is the same as that of the remaining substations, except that it is of larger capacity.

In the generator room are two switchboards of white marble, mounted on an angle-iron frame. One of these boards contains the instruments and regulating apparatus for the alternating current output of the entire plant and the other is a typical substation switchboard. The leads from each of the generators are led direct to a generator panel. Each leg of the three-phase circuit from each generator is connected through a single pole single-throw 2,000 ampere switch to one of the low potential busbars which run the entire length of the board, and two of the legs of the circuit from each generator are provided with 2,000 ampere non-automatic circuit breakers. There are three alternating current ammeters on each generator panel reading up to 2,500 amperes, one in each phase, and two 750 k.w. indicating wattmeters are connected between the phases of each machine. The field circuit of each generator is led to its corresponding panel and has in its circuit a field rheostat and a 200 ampere direct current ammeter. The standard Westinghouse synchronizing apparatus, ground detector and pilot lamps are also placed on each-generator panel.

The load panel, placed next to the generator panels, contains the instruments for reading the total current on the bus-bars. There are three alternating current ammeters, one in each leg of the circuit reading up to 10,000 amperes, two direct reading Niagara type wattmeters, and one 5,000 k.w. integrating polyphase recording wattmeter reading the station output.

A three-phase circuit is tapped from the low potential bus-bars to each of the low-potential alternating current feeder panels, each leg of the circuit running to a single pole switch, and two of the legs having automatic circuit breakers in them. The lines then run through ammeters to the 250 k.w. step-up transformers in the basement where the current is stepped up to 16,000 volts. The high potential lines pass through circuit breakers on leaving the transformers, and then go out over the four sets of high-potential feeder lines. A lightning arrester is connected in each high-potential line as it leaves the building.

The two remaining panels on this board are for the exciters, one for the motor-driven and the other for the steam-driven. The engine-driven exciter panel contains a 150 volt scale voltmeter and an ammeter reading up to 500 amperes for the field circuit. The exciter circuit passes through a circuit breaker to the pair of 125 volt field bus-bars which run behind the generator panels. From these bus-bars the circuits are led to each generator field through a pair of plug switches, an ammeter and a field rheostat. This exciter panel also contains a rheostat for the shunt field of the exciter and a double throw two-pole switch, the function of which is to connect either the exciter or the 125 volt storage battery section to the field bus-bars as desired. The motor driven exciter panel contains a switch for the induction motor, a rheostat for the exciter field, an ammeter and two two-pole knife switches.

None of the alternating current ammeters or wattmeters have their current coils directly in the circuit, but take current from the secondaries of series bus-transformers in which the bus-bar forms the one-turn primary—the ratio of conversion of current being 8,000/5 in the instruments on the load panel and 20,000/5 on the generator panel. In calibrating the ammeters, a standard Stanley hot-wire ammeter, with shunts, was put in series with the secondaries of the transformers and the instrument on the board. In calibrating the wattmeters, the current coil of a standard Weston wattmeter was connected in series with the current coil of the switchboard instrument, and the pressure coil connected in parallel. As the pressure coil of the Weston is built for 150 volts, German silver resistance had to be connected in series with it and its value as a multiplier found by calibration with a Kelvin balance. The station voltmeters were connected in parallel with a standard Weston alternating and direct current voltmeter for calibration. All standards used in calibration were calibrated by means of a Kalvin balance and all the test readings corrected accordingly. As the instruments had to be calibrated, and connections made while the plant was in operation, and as it was difficult to get readings over a very wide range without spending time in waiting for the load to vary, it took almost two weeks to complete the calibrations.

METHOD OF PROCEDURE.

BOILER TEST.

Water.—In order to ascertain the amount of water used in the boilers, it was decided that the oridnary method of weighing the water by barrels was altogether impracticable, so a Venturi meter was installed in the feed water main above the boilers. This meter is nothing more nor less than a graduated nozzle‘ so arranged that pressure gages may be inserted at the throat and at the up-stream end. By the difference in the pressure readings of these gauges, noted every 15 minutes, and the known area of the nozzle, the cubic feet of water flowing in a given time may be calculated. The temperature of the water was also taken.

Prior to the test the Venturi meter was calibrated in the Engineering laboratory of Purdue University. The meter was connected to a pump and means provided whereby the up-stream pressure was kept constant at about the boiler pressure maintained in the boiler room at Anderson, while the throat pressure was varied. In this work of calibration a weir was made use of and hook gauge readings were taken, so that the actual rate of flow of water could be calculated for the various differences in pressure of the meter gauges.

For the determination of the amount of water used by the boilers during a test the curve of flow over the weir (Fig. 1) was plotted against the differences in the indications of the gauges on the Venturi meter and from this curve the actual rate of flow of water to the boilers was found from the records made every fifteen minutes during the test. A curve was then constructed, the ordinates of which represent the rate of flow of water plotted against time. By integrating this curve for any desired interval of time the number of cubic feet of water used during the said interval can be determined and the weight of the water used found by multiplying by 60.3 the density of water at 185° F., the feed water temperature.

Coal.—The method employed in weighing the coal was to close all the coal chutes and but one to take all the coal used in the test from one bin. Coal was allowed to fall to the floor instead of into the stoker hoppers, and was then thrown into wheelbarrows and weighed; the contents of the barrows was then dumped on the floor in front of the several boilers and thrown into the stoker hoppers by hand. In this way the accurate weight of coal used was kept on the coal log together with the time of weighing, so that a curve of coal against time could be plotted.

A sample of coal was taken every 12 hours by the A. S. M. E. method, and tested for moisture and calorific value.

Special.—A thermometer inserted in the feed-water pipe registered the temperature of the water entering the heater, while a thermometer inserted in the Venturi meter registered the temperature of the water entering the boiler.

The barometric pressure was recorded by an aneroid barometer placed in the engine room.

The boiler pressure was read from the gauge over the central pair of six boilers which were in service during the three days' test, though all of the boiler gauges were carefully calibrated prior to the test.

The engine room temperature was indicated by a thermometer hung from one of the voltmeter brackets in front of the switchboard but not in proximity to any of the switches or cables.

The initial steam pressure, receiver pressure and vacuum in inches were read from the gauges on the engine board, while the engine speed was determined with revolution counters in the usual manner.

The time of starting and stopping all auxiliary engines was carefully noted during the test on the supposition that this record would be of value when considered in connection with a separate test to be made of the auxiliaries to determine the amount of steam used by them.

Subsequently, owing to defects in the valves of the boiler room pipe line, it was found impossible to saparate a pair of the boilers from the remainder of the battery effectively, and consequently the special test of the auxiliaries had to be given up.

As stated below, in figuring out the net engine economy an allowance of 15 per cent. has been made for the amount of steam consumed by the auxiliaries.

The water level in the boilers was kept as nearly as possible at the same level throughout the test and was noted to be the same at the end as at the beginning of the test.

Engine Test.—The engines were indicated at both ends of both cylinders, pantagraph reducing motions being exclusively employed.

Indicator diagrams were taken at intervals of fifteen minutes throughout the test, care being taken to get plain diagrams simultaneously on all cylinders. The r.p.m. was also carefully noted on the engine log together with steam gauge readings, vacuum gauge readings, receiver gauge readings and barometer readings.

The drain pipes from the separators were disconnected from the Holly system and so arranged that the drip could be weighed, thus affording a means of calculating the percentage of moisture in the steam.

An account was kept of the time the exciter engine was run, but the time was so short that it did not figure in the results.

Generator Test.—On the switchboard, readings of the instruments on each generator panel were noted, *i.e.*, of an ammeter, both indicating wattmeters and of the ammeter in the exciting circuit. On the load panel, in addition to these readings, the reading of the polyphase integrating wattmeter was also taken. Other readings recorded were—the bus-bar voltage, the exciter voltage and the total field current.

Each generator output is given by the sum of the two indicating wattmeters on each generator board. The total output of the generators, in a similar manner, is obtained from the readings of the two indicating wattmeters on the load panel, and the sum of these two load panel wattmeter readings should equal the sum of the four indicating wattmeter readings on the generator panels. The great inertia of the moving parts of the wattmeters and the insufficient number of observers, making it impossible to take all readings at the same instant, will probably account for any discrepancies in this part of the data, as a very small swing over the scales will make an appreciable error. In most cases the sum of the four wattmeter readings check very closely with the load panel readings. In several instances use was made of this fact in detecting errors in the load panel readings. For instance, in plotting the engine and generator output, the two curves were found to follow each other very nicely. In several instances, however, the engine would indicate a large instantaneous load while the load panel readings for the same time would not indicate a corresponding increase in the generator output; recourse to the generator logs would invariably either check the load panel readings and thus show the error in the engine output due to the fact that the cards were not taken at the same instant

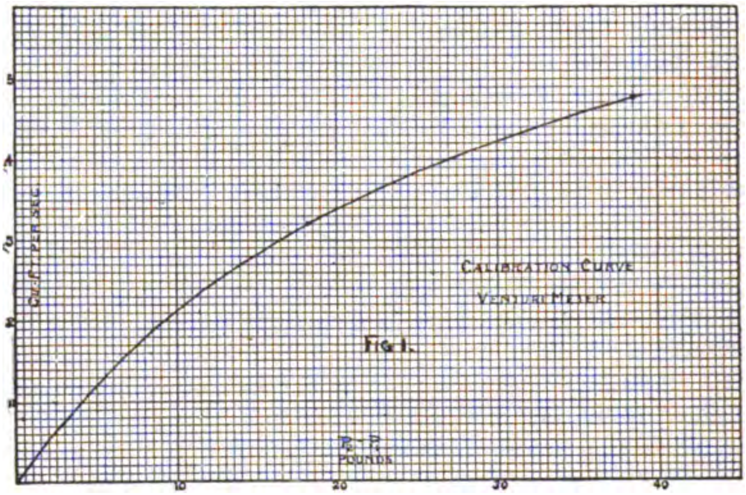


Fig. 1.

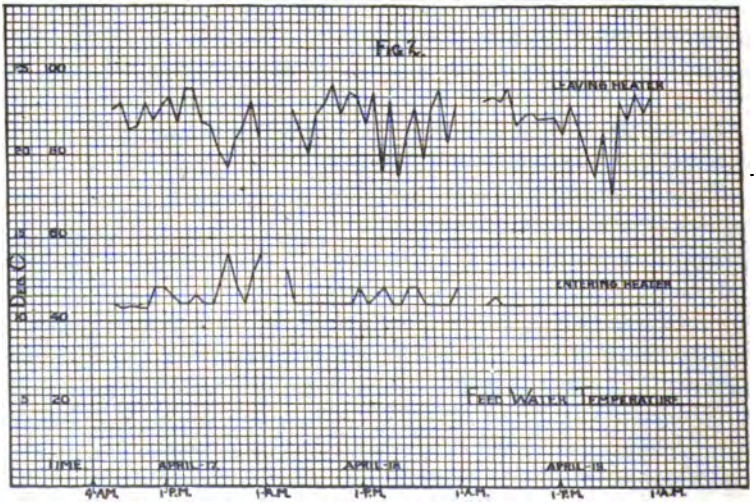


Fig. 2.

or would check with the engine output showing the load panel readings to be in error.

Results of the Engine and Boiler Tests.—In the records which follow it is not attempted to give anything more than a summary of the records which were made on the three days during which the tests were in progress. The results here presented. are deemed to be sufficiently accurate inasmuch as the tabulated data have been worked over twice and in some instances three times in order that the possibility of appreciable error entering at any point might be avoided.

In Table I. is given a resumé of the data covering the barometric pressure, the boiler pressure and the feed water temperature. From this table it will be seen thatthe variations in the barometric pressure were unimportant. The variations in the steam pressure were, however, at times quite marked, In Fig. 3 a graphic record shows the character of these pressure variations. On each day during the afternoon the pressure fell off quite markedly owing to the fact that late in the day the load on the station comes on rapidly. The demand on the station was frequently very heavy for a short time, and as the firing had to be adjusted to the average load, fluctuations necessarily took place in the boiler pressure. The average boiler pressure is very close to 140 pounds; the maximum record being 150 pounds and the minimum 125 pounds during service hours.

TABLE I.

GENERAL AVERAGES.

PRESSURES AND TEMPERATURES.

	April 17.	April 18.	April 19.	Total.	Highest.	Lowest.
Barometer in inches Hg........	28.63	28.62	28.61	28.62	28.70	28.55
Feed water entering heater°C...	12.00	11.34	11.02	11.45	14.0	10.8
Feed water entering boiler °C...	88.7	88.5	88.6	88.6	97.0	70.8
Boiler pressure lbs. per sq. in...	137.7	141.5	139.4	139.5	150.0	125.0

The temperature of the water entering the heaters was practically constant at 11° centigrade throughout the tests. The temperature of the feed water leaving the heaters was subject to variations similar in character to those in the boiler pressure, but more marked in degree. These variations in the temperature of the feed water leaving the heaters and entering the boilers is, however, largely due to a different cause. Since the feed water is heated by the exhaust from the auxiliaries its temperature is dependent upon the number of these auxiliaries in service. Late in the day some of the auxiliaries, especially the coal crushing and the conveying apparatus, are thrown out of service. During the test the temperature of the feed water entering the boilers varied from 96° centigrade to 70° centigrade.

The general results of the boiler tests are given in Tables II. and III. and recorded graphically in Figs. 4, 5 and 6. During all three days of the tests the supply of water to the boilers was fairly uniform, at 50,000 pounds per hour. This rate was exceeded slightly on all three days, and on April 19th the average ran up to 57,000 pounds per hour. The rate at which the coal was fired, however, was subject to rather marked fluctuations. On the first morning of the tests, owing to the facts that the coal handlers were " green " and the usual procedure in the station changed on account of the coal chutes being thrown out of commission and the coal shoveled from the boiler room floor by hand, coal was fired at a very high rate. Subsequent to the first morning, however, no irregularities of any importance occurred, as, during the remainder of the test, the amount of coal on the boiler room floor for delivery to the grates was supervised by the head fireman, and kept fairly proportional to the load on the station. This is especially true of April 18th and 19th.

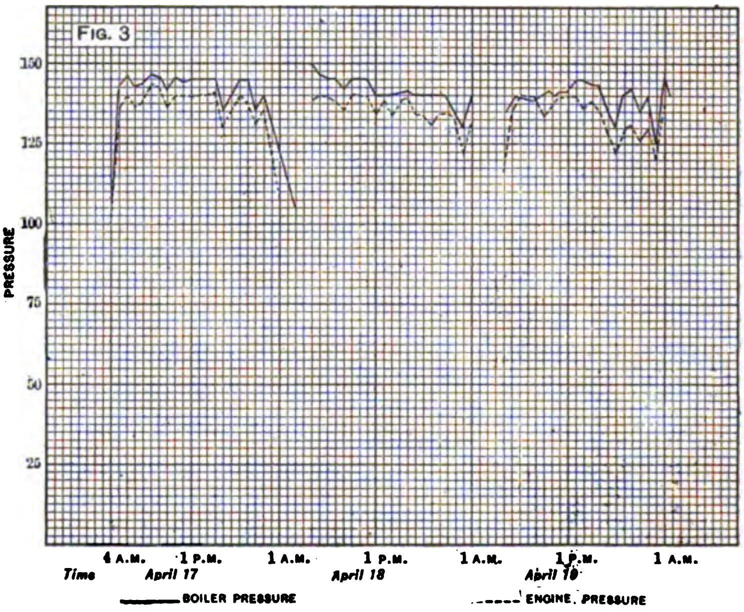


Fig. 3

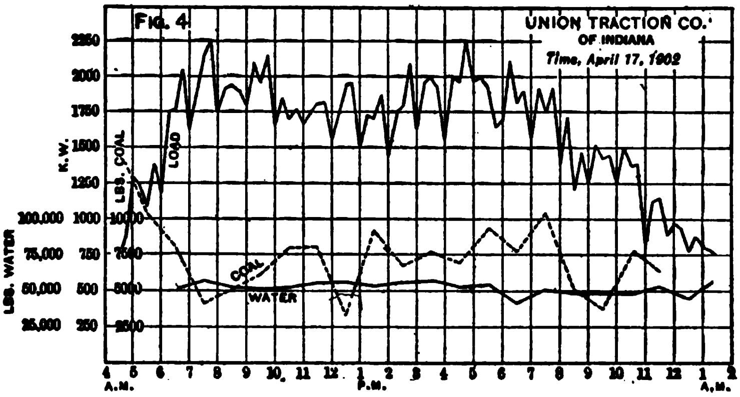


Fig. 4

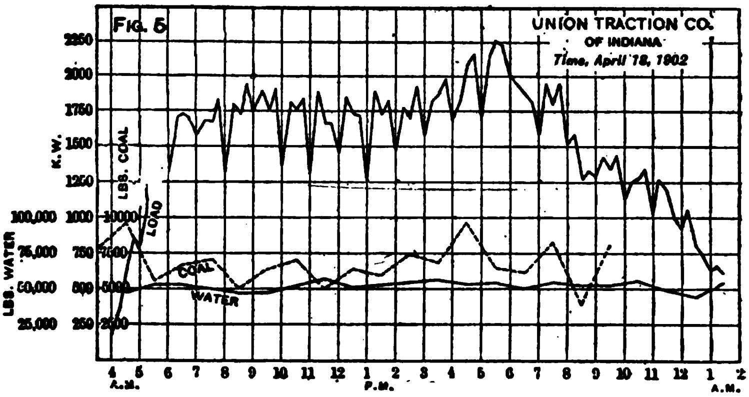


Fig. 5

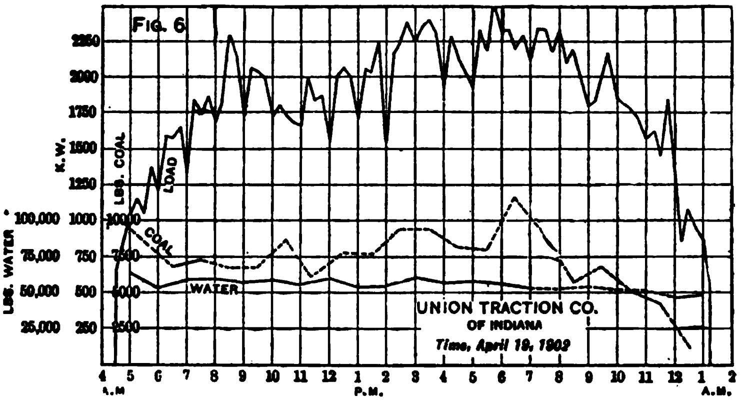


Fig. 6

It may be well to add a few words in explanation of the boiler test data of Table III. Item 4 is an assumption, owing to the fact that it was thought no dependence could be placed upon the determinations of the moisture in the coal made from the samples taken, inasmuch as, when dumped upon the floor, the coal was in a relatively dry condition on account of having been stored over the boilers for a considerable number of hours previous to its being used. It was impossible, however, to seal up the samples at once, and consequently they had ample opportunity to absorb a considerable amount of moisture.

Owing to the fact that Item 27 of Table VIII., which shows the equivalent water evaporated per pound of combustible from and at 212°, is rather high, it is thought that the actual amount of moisture in the coal was less rather than greater than the assumed value of 6 per cent. If the extreme condition is assumed and the coal taken to be dry when fired under the boilers. Item 27 will be reduced from 12.30 pounds evaporated per pound of combustible to 11.65 pounds evaporated per pound of combustible, which is more nearly in accordance with the claims of the builders of the boilers.

TABLE II.

DATA ON BOILERS AND FURNACES.

Number of boilers	8
Kind of boilers	Babcock & Wilcox.
Capacity of boilers	400 h.p. each.
Number of tubes, per boiler	102.
Size of tubes	4" diameter.
Number of drums, per boiler	2.
Diameter of drums	3'.
Length of drums	16'.
Area water heating surface, per boiler	4000 square feet.
Kind of furnace	Babcock & Wilcox standard.
Area grate surface	66 square feet.
Kind of fuel	Brazil block, mine run.
Method of starting and stopping test	Standard, A. S. M. E. code.

Results reported by the Babcock & Wilcox Company indicate an average performance of 11.4 pounds of water evaporated from and at 212°, per pound of combustible; the test figures, therefore, indicate an excellent performance. But few reports come to us of boilers showing a maximum evaporation above 12 pounds of water evaporated per pound of combustible from and at 212°, and 12.5 pounds is about the highest evaporation that can be obtained from high-grade steam fuels. A few reports have shown as high a maximum as 13.25 pounds of water evaporated per pound of combustible, but it is safe to say that an average record made during three days test at Anderson, Ind., of 12.3 pounds evaporated per pound of combustible from and at 212° is an excellent showing under conditions of variable load.

Recent tests upon electric street railway properties show an economy somewhat less than this. For instance, a test made of the Oshkosh Electric Railway System* about one year ago by Prof. Swenson of Wisconsin University and some of his students shows the boiler plant to have developed an economic evaporation of 10.6 pounds of water per pound of combustible, from and at 212° F. The boilers in this case were of Babcock & Wilcox manufacture.

TABLE III.

RESULTS OF BOILER TESTS.

No.	Quantity	April 17.	April 18.	April 19.	Total.
1	Date of trial	April 17.	April 18.	April 19.	Total.
2	Duration of trial	24 Hrs.	24 Hrs.	24 Hrs.	72 Hrs.
3	Weight coal as fired	144,500	145,000	146,000	435,500
4	Moisture in coal	6%	6%	6%	6%
5	Total weight dry coal	135,800	136,500	137,200	409,300
6	Total ash and refuse	16,460	16,540	16,640	49,640
7	Per cent. ash and refuse	11.4	11.4	11.4	11.4
8	Total combustible	119,340	119,760	120,560	359,660
9	Dry coal per hour	5,650	5,700	5,730	5,690
10	Dry coal per sq. ft. grate per hr	14.25	14.40	14.48	14.39
11	Total water to boiler	1,242,000	1,256,600	1,256,600	3,755,200
12	Water actually evap.	1,229,700	1,244,000	1,244,000	3,717,700
13	Equiv. from and at 212	1,487,000	1,505,000	1,505,000	1,497,700
14	Water per hour, corrected	51,200	52,000	52,000	51,700
15	Equiv. evap. per hour	62.000	62,800	62,200	62,400
16	Equiv. per sq. ft. grate	157	158	158	157.8
17	Average steam pressure	137.7	141.5	139.4	139.5
18	Temp. feed entering boiler	88.7	88.5	88.6	88.6
19	Moisture in steam	.99%	.99%	.99%	.99%
20	H. P. developed	1,800	1,820	1,820	1,805
21	Builders' rated h.p	2,400	2,400	2,400	2,400
22	Per cent. b.r.h.p. developed	75	75.8	75.8	75.3
23	Water evap. per lb. coal	8.51	8.58	8.52	8.53
24	Equiv. evap. per lb. coal	10.21	10.30	10.22	10.24
25	Equiv. evap. per lb. dry coal	10.86	10.96	10.89	10.90
26	Equiv. evap. per lb. combustible	12.27	12.36	12.29	12.30
27	Calorific value coal	12,500	12,500	12,500	12,500
28	Calorific value combustible	14,100	14,100	14,100	14,100
29	Efficiency boiler based on coal	79.1	79.7	81.1	79.6
30	Efficiency boiler based on combustible	83.9	84.6	84.3	84.3
31	Economy feed water heater	6.15	6.20	6.23	6.19
32	Cost per ton of 2,000 lbs.	$1.35	$1.35	$1.35	$1.35
33	Cost of coal required to evaporate 1,000 lbs. of water from and at 212°	$.0655	$.0651	$.0657	$.0654

An elaborate test was made in May, 1898, by the students of the Massachusetts Institute of Technology on the Harvard Power

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**Street Railway Review*, September 15, 1898.

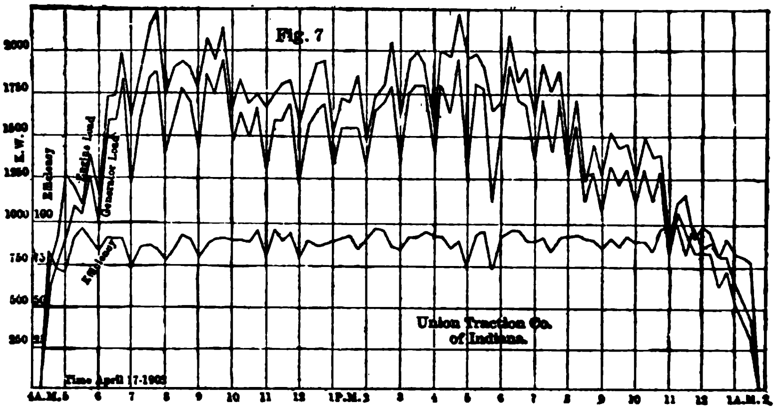


Fig. 7

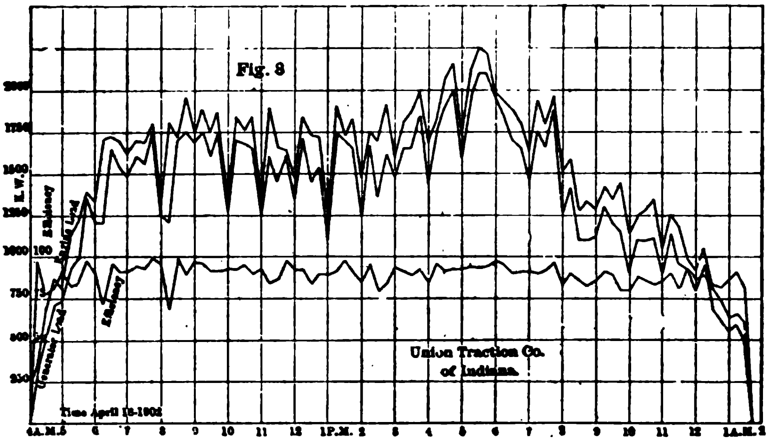


Fig. 8

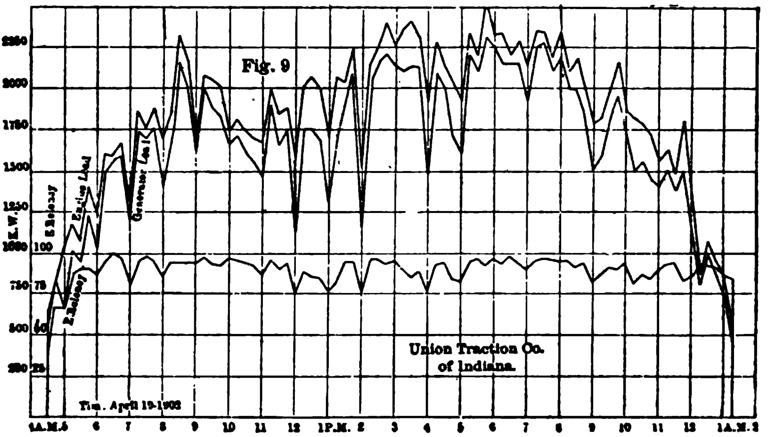


Fig. 9

Station of the Boston Elevated Railway Company. This station is equipped with six Babcock & Wilcox water-tube boilers, developing a total capacity of 3,000 h.p. The report shows that 11.3 pounds of water were evaporated from and at 212° per pounds of combustible, there being 1 per cent. of moisture in the coal and 5.9 per cent. of ashes and clinkers. Other points of comparison are that in the Harvard test the average boiler pressure was 168 pounds against 140 pounds at Anderson. The average temperature of feed water entering the boilers was 209° F. at Harvard against 191° F. at Anderson, and the heat gained in heaters and economizers as compared to the total heat acquired was 7.6 per cent. at Harvard against 6.2 per cent. at Anderson. The Harvard test offers the best comparison with the Anderson tests of any that has come to the attention of the authors, and the Anderson tests show the boilers to have developed a higher economy.

Inasmuch as the conditions governing the loading of these stations were presumably similar in character, the Harvard and Anderson tests may be considered fairly representative of American practice on electric roads operating under conditions approximating those which obtain in the suburban traffic service of steam railroads.

The efficiency of the boilers expressed in terms of the total calorific power of the coal is 79.6 per cent. This is a very creditable showing in view of the fact that but 75.3 per cent. of the builders' rating was developed by the boilers.

The adjustment of the boiler capacity to the requirements of the station is better than these figures indicate, inasmuch as, owing to the fluctuating character of the load, the demand upon the boilers frequently equalled—and at times exceeded—their rated capacity.

ENGINES.

The efficiency developed by the engines during these tests is not so good as might have been expected. During the major portion of the time two engines were in service. Engine No. 1 was operated for 24¾ hours. Engine No. 2 for 41¾ hours, and Engine No. 3 for 55 hours. Notwithstanding the rapid and excessive fluctuations in the load, the same was remarkably well divided between the engines, and comparatively little surging can be traced from the records. In Fig. 10 curves are plotted showing the distribution of the load between engines No. 2 and No. 3 on April 17th. If these curves are scrutinized in connection with the load curve of Fig. 7, it will be seen that the division of the load between the two engines is almost perfect, and that the load on the station was comparatively steady when considered as representing street railway performance during the noon hours. Late in the day, when the load had fallen off and the engines were relatively lightly loaded, a slight see-sawing is noticeable, particularly between 6 and 9 P. M.

Curves 8 and 9 show the character of the load on the station during the second and third days of the test, and it will be noticed that the variations in the load were much more marked on these days than on the first day. The variations are reflected in Curves 11 and 12, which show the division of the load between Engines 2 and 3 on both days. On April 18th Engine No. 3 varied considerably in the amount of the load it carried relatively to the amount carried by Engine No. 2. This is marked between the hours of 4 and 8 P. M. During this time the load on Engine No. 2 was comparatively steady, while the variations in the load were taken up by Engine No. 3. That the behavior of the engines on April 18th is not so good as that on April 17th is attributed to there being much heavier changes in the load on the station on the 18th than on the 17th. On April 19th, as shown in Fig. 9, the changes in the load were particularly heavy. Especially is this true at noon, 2 and 4 P. M. Each of these variations is indicated in Fig. 12 by very marked fluctuations in the load of Engine No. 3, which at 8.30 o'clock, when a sudden load was thrown on the station, took the peak as well as the depression which followed at 9 o'clock. From indications contained in the distribution load curves shown in Figs. 10, 11 and 12, it is fair to assume that Engines 1 and 2 were better regulated and adjusted for their work than was Engine No. 3. It is hardly thought that the bad behavior of Engine No. 3 can be entirely attributed to the fluctuations in the load but rather to some imperfection in the governing mechanism of the engine whereby the peripheral velocity of its fly wheel was accelerated or retarded relatively to the velocity of the periphery of the fly wheel of Engine No. 2. In Fig. 14 a portion of the engine data has been plotted for the purpose of illustrating the load distribution between the high and low pressure cylinders and between the h.e. and c.e. of the cylinders. The high pressure cylinder of Engine No. 2 takes most of the load, but the division of the load between the h.e. and c.e. of the cylinders is fairly uniform. In the case of both cylinders the c.e. develops slightly higher power than does the h.e.

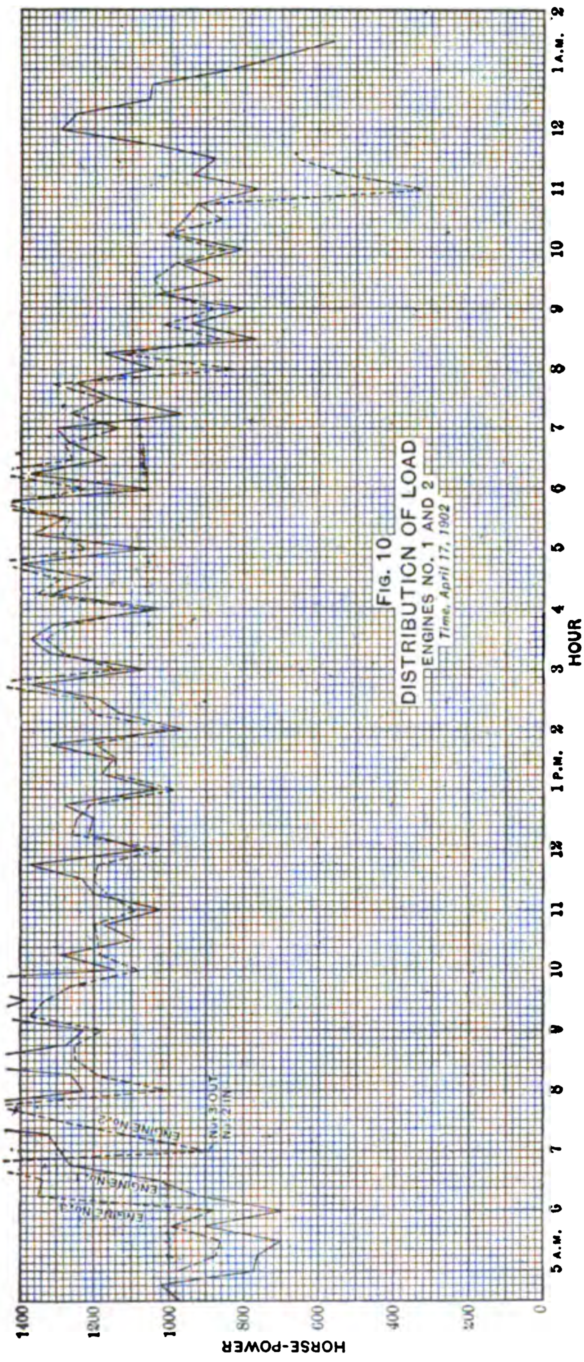


FIG. 10

DISTRIBUTION OF LOAD

ENGINES NO. 1 AND 2

Time, April 17, 1902

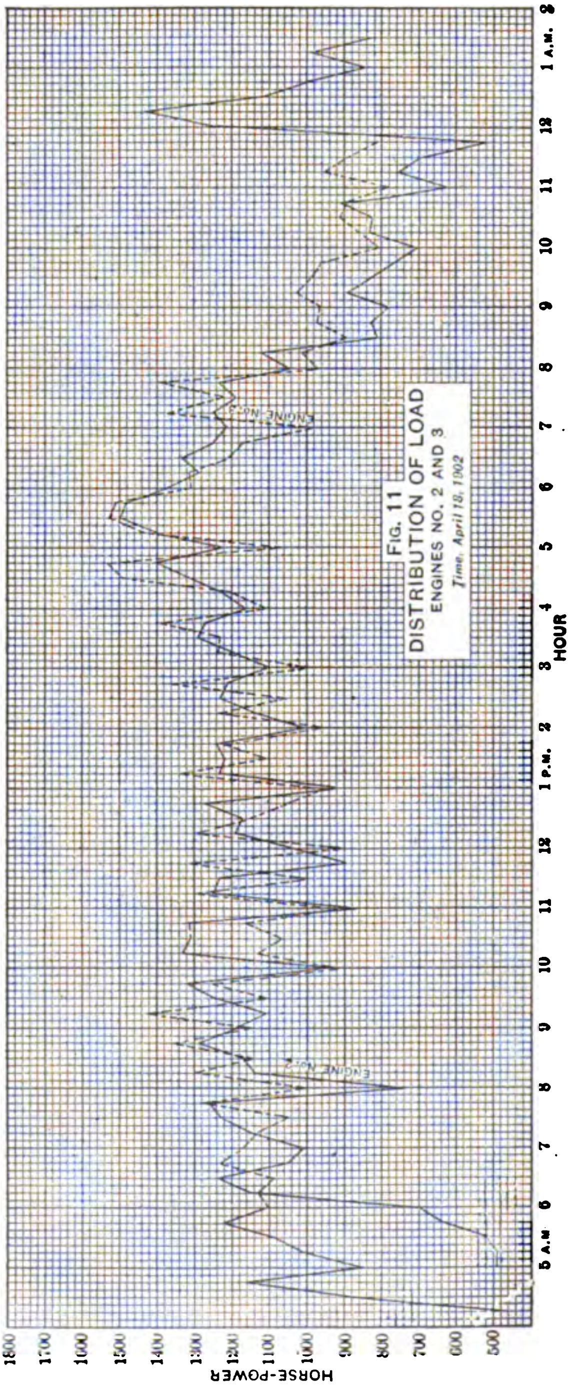


FIG. 11
DISTRIBUTION OF LOAD
ENGINES NO. 2 AND 3
Time, April 18, 1902

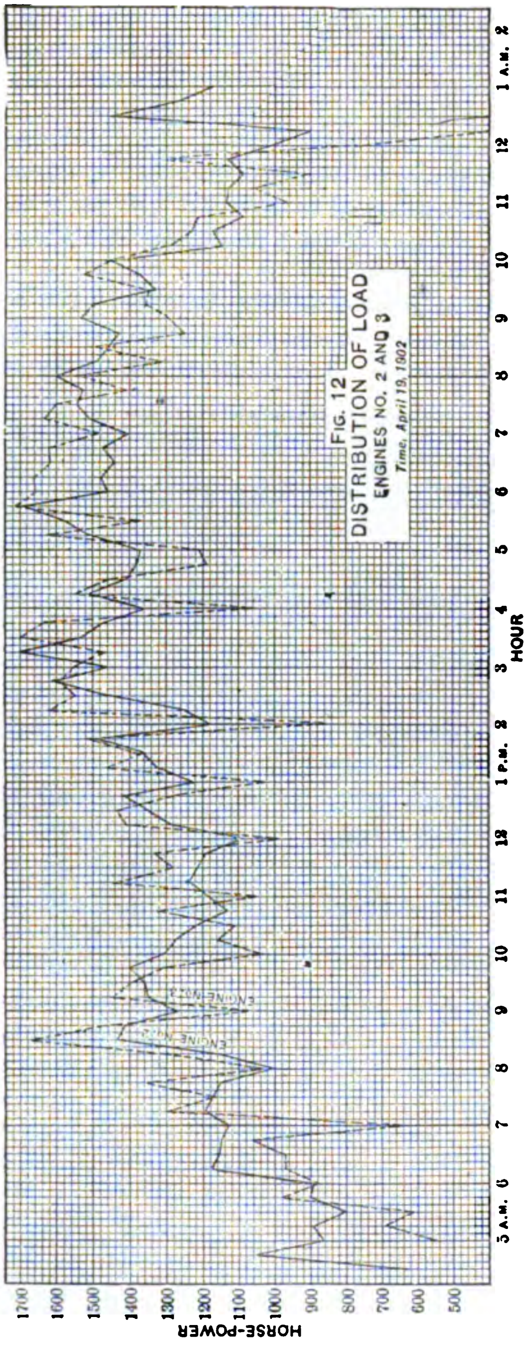


FIG. 12
DISTRIBUTION OF LOAD
ENGINES NO. 2 AND 3
Time, April 19, 1902

In Fig. 15 a similar graphic presentation is given of the distribution of the load in Engine No. 3. The high pressure cylinder here also develops the greater amount of power, and in the c.e. of the cylinders slightly more power is developed than in the h.e.

Figs. 14 and 15 cover the same hours of April 19th, and comparing them it is very evident that the speed regulation of engine No. 3 was in no wise equal to that of engine No. 2, owing to the fact that the changes of load on engine No. 3 are greatly in excess of those on engine No. 2.

As a matter of general interest, an effort has been made to determine the efficiency of conversion of the combined generating units at different loads. It is necessarily quite impossible that the efficiencies given for any determined load by taking the ratio of the total output in k.w. to the total i.h.p. should be the same. The energy stored in the fly-wheels takes up a considerable portion of the fluctuation in the electrical load on the station, and, furthermore, errors are always introduced into recorded data by observers in different parts of the station failing to read their instruments at exactly the same instant.

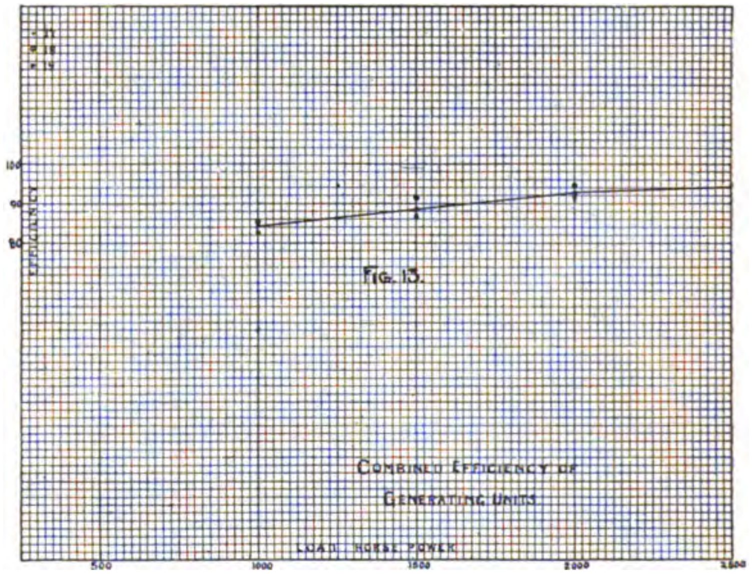


FIG. 13.

In approximating the correct efficiency curve a series of averages has been taken of the instantaneous efficiencies of conversion worked out from the indicator cards and the simultaneous switchboard readings. Fig. 13 shows the result of taking these averages. In these calculations any load between 87.5 and

112.5 per cent. was assumed to be full load; loads between 62.5 and 87.5 per cent., three-quarters load; and between 37.5 and 62.5 per cent., one half load. All points above 112.5 per cent. were assumed to be 25 per cent. overload.

The great number of readings available made it possible to secure a very close approximation of the efficiency of the generating units and the efficiency curve of Fig. 13 probably quite accurately represents their performance. The curve of Fig. 13 shows that at full load the generating units developed an efficiency of about 93 per cent. and that at one-half load theydeveloped an efficiency of about 84 per cent. These values are excellent and indicate a high type of machinery.

The average efficiency of the generating units, *i.e.*, the ratio of the generator curves and the i.h.p. curves of Figs. 7, 8 and 9 is nearly 90 per cent., as shown in Item 12 of Table VIII. The efficiency curves of Figs. 7, 8 and 9 give fairly constant results. In some instances the instantaneous efficiency falls as low as 70 per cent., and at times it rises above 95 per cent. No values however, occur above 100 per cent., and this is a matter for remark when it is remembered that a large amount of energy is stored in the fly wheels and that, where the load is varying rapidly, it is not an unusual thing for the readings of the electrical instruments to show an amount of power delivered in excess of the indicated power of the engines.

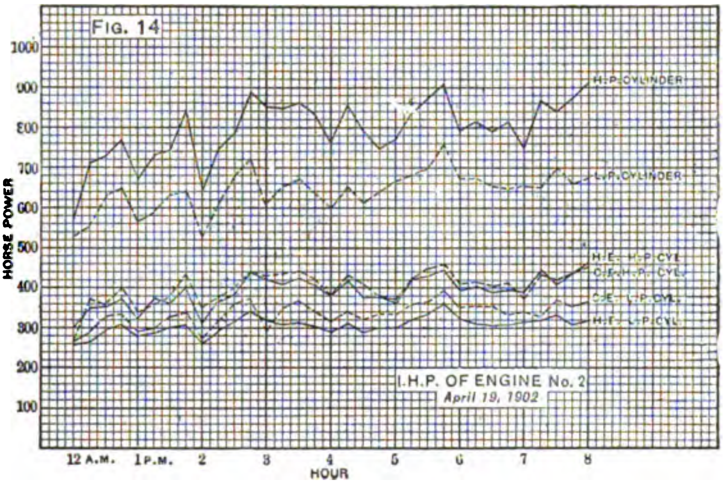


FIG. 14

In the Anderson tests points of high efficiency follow very closely points of high load on the station, the low efficiencies coming at points of low load. This is as it should be and indicates good regulation.

In Table IV. results are recorded which show the economy of the station in terms of the coal and steam required to develop an i.h.p. hour and a k.w. hour for the different days and for the whole test. It must be remembered that the results here recorded include the steam used by the auxiliaries. The average coal consumption per i.h.p. per hour is 2.85 pounds. The best economy was developed on the 19th, when an average of but 2.65 pounds of coal was required in developing one i.h.p. This is probably due to the fact that the load was heavy and quite steady for a number of hours on the afternoon of the 19th.

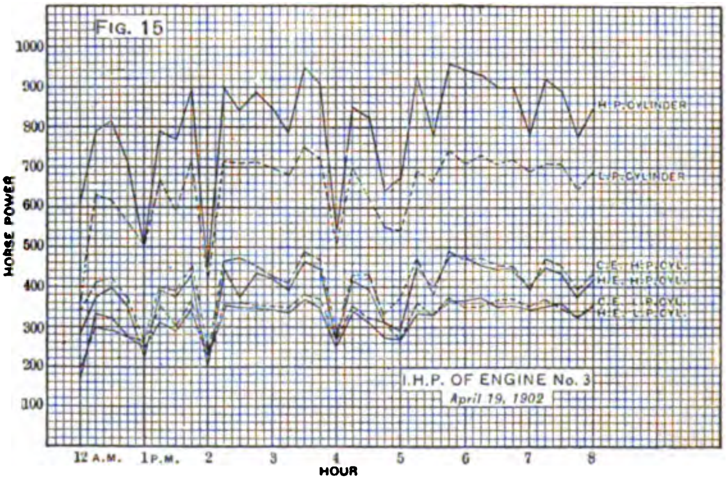


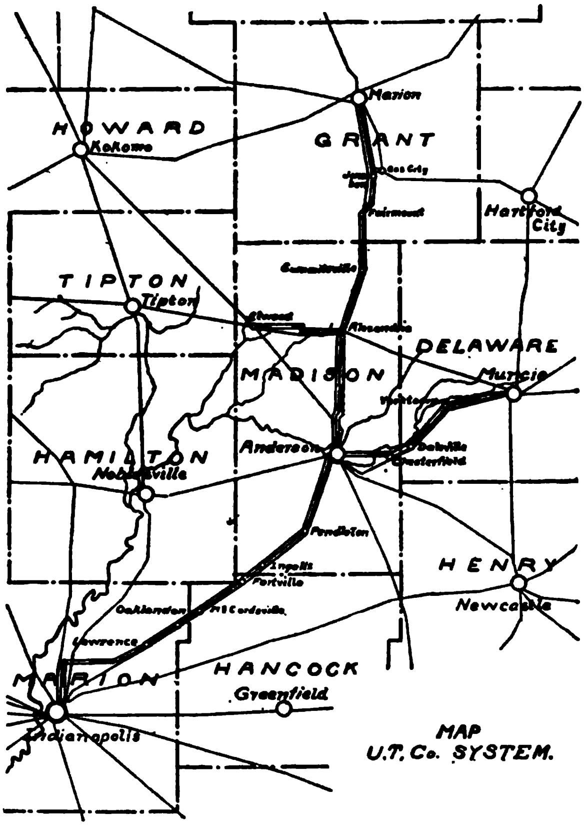
Fig. 15

The high value of 3.01 pounds of coal per i.h.p. per hour shown on the 18th comes from the fact that on the 18th the variations in the load were heavy and there was no balancing period of heavy load during the latter part of the day. In other words, the fires had to be built up to carry the heavy load at 5 o'clock; while immediately after 5 o'clock the load fell off. On the 19th the period of heavy load extended on until 9 o'clock, beginning as early as 2 o'clock in the afternoon.

The weights of steam required to develop an i.h.p., as given in Table IV., vary from 22.6 pounds on the 19th to 23.9 pounds on the 17th. These values are high, even though they include the steam used by the auxiliaries.

In approximating the actual coal and steam economy of the engines and generators the assumption has been made that the auxiliaries require 15 per cent. of the steam generated. It is not believed that this percentage is too high, in view of the fact that a considerable amount of power is developed by relatively small engines in operating the crushing and conveying machinery, the automatic stokers, pumps, etc.

A great deal of data as to the amount of power which auxiliaries consume is not availiable. Results recently published by C. D. Taite and R. S. Doune* give a comparison between steam and electrically operated auxiliaries in central stations and show that electrically operated auxiliaries require from 6.5 to 8.5 per cent. of the total power generated, whereas steam driven auxiliaries require upwards of twice this amount.



MAP
U.T. Co. SYSTEM.

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*A paper presented at a meeting of the British Institution of Electrical Engineers, April 7, 1903.

The records in Table V. show that on April 19th an i.h.p. hour was developed with an expenditure of 2.25 pounds of coal; and the average for the three days shows that an i.h.p. hour was developed by 2.42 pounds of coal. The average of seven tests of compound condensing Corliss, Greene, McIntosh and Seymour, and simple valve motion compound engines, reported by Prof. R. C. Carpenter of Cornell University in a paper read at the Cornell meeting of the New York Street Railway Association, 1899, is 2.6 pounds of coal per i.h.p. per hour.* The lowest value reported by him is 1.8 pounds of coal per i.h.p. per hour and the highest 4.06 pounds of coal per i.h.p. per hour. The low value is credited to an engine of 2,000 h.p. capacity and the high value to an engine of 825 h.p. capacity. By comparison with these results the performance of the engines at Anderson is very creditable.

TABLE 4.

RESULTS OF TESTS MAKING NO ALLOWANCE FOR STEAM USED BY AUXILIARIES. TOTAL COAL AND WATER IS CHARGED TO ENGINES AND DYNAMOS OF MAIN GENERATING SETS.

Date Apr.	Coal fired lbs.	Water delivered to boiler lbs.	I. H. P. hours devel-oped.	Lbs. coal per I.H P. per hour.	Lbs. steamper I.H.P. per hour.	K. W. H. devel-oped.	Lbs. coal per K.W. per hour.	Lbs. steamper K.W. per hour.
17	144,500	1229700	51300	2.82	23.9	33000	4.38	37.2
18	145,000	1244000	48000	3.01	25.9	32200	4.50	38.6
19	146,000	1244000	55000	2.65	22.6	36700	3.98	33.9
3 days.	435,500	3717700	153820	2.85	24.25	101900	4.28	36.8

As regards steam economy, Table V. shows the best performance of the Anderson engines to have been on April 19th when they developed an average economy of 19.7 pounds of steam per i.h.p. per hour. On this day the average i.h.p. of each engine was 1,230 and the maximum h.p. developed 1,690. The engines were, therefore, on the average, working under but 60 per cent. of their maximum capacity. Under these conditions an economy of 19.7 pounds of steam per i.h.p. per hour is not so bad, and, in fact, may be taken as representing creditable performance. The average of the tests reported by Prof. Carpenter was 18.8 pounds per i.h.p. per hour. The 2,000 h.p. engine before referred to developed an i.h.p. on 14.5 pounds of steam while the 825 h.p.

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*The Fuel Economy of Railway Engines, *Street Railway Review*, Oct., 15, 1899.

engine required 22.7 pounds of steam. Unfortunately the conditions of loading are not specified in these cases so that the comparison fails in some particulars.

In the case of the test on the Harvard station previously mentioned of engines made by E. P. Allis Company, each of which has a nominal capacity of 1,800 h.p., the engines are shown to have developed an i.h.p. with a consumption of between 14 and 15 pounds of water. This is a high economy for street railway work. Unfortunately no curves or other data are given from which any determination of the character of the variations in the load upon the Harvard station during the tests can be made. On May 10th the Harvard test record shows the engines to have developed an i.h.p. on 14.05 pounds of steam when the engines were under an average load amounting to only 72 per cent. of their normal rating. This performance is better than anything reported by Prof. Carpenter and shows a performance 29 per cent. better than that of the Rice & Sargent Corliss engines in the Anderson station. In operating efficiency, however, the machinery in the Anderson station seems to be the equal of that in the Harvard station, as both average 90 per cent. with the per cent. of loading in favor of the Harvard station.

TABLE 5.

RESULTS OF TESTS FIGURED ON THE ASSUMPTION THAT 15 PER CENT. OF THE STEAM GENERATED WAS USED BY THE AUXILIARIES.

Date, April.	Lbs. coal per I. H. P. per hour.	Lbs. steam per I. H. P. per hour.	Lbs. coal per K. W. per hour.	Lbs. steam per K. W. per hour.
17	2.40	19.22	3.72	31.6
18	2.56	22.0	3.82	32.8
19	2.25	19.7	3.38	28.8
3 days.	2.42	20.61	3.64	31.3

As also tabulated in Table V., the test results show that 3.38 pounds of coal and 28.8 pounds of steam are required to develop 1 k.w. hour under the most favorable conditions. These values are somewhat higher than those reported for several street railway power stations in the *Street Railway Review* of February 15, 1898, September 15, 1899, and July 15, 1900. The data reported by the Metropolitan Elevated of Chicago show an economy varying from 2.19 to 5.78 pounds of fuel per k.w. hour. The average of the reports, however, runs about 2.7 pounds of coal per k.w. hour. In these reports bituminous coal is specified whereas block coal of low grade is used at Anderson. In the test reported by E. P. Roberts & Co. made on October 5, 1901,* on the Dayton and Northern Traction Co.'s system it is specified that the engines developed an i.h.p. on 16.3 pounds of dry steam per hour and that one k.w. hour was developed on 3.7 pounds of coal per k.w. hour. The efficiency of the boiler and furnace was 65 per cent. Comparing these results with those of the Anderson tests, the steam economy per i.h.p. is better, the coal economy per k.w. hour worse and the efficiency of the boilers less. The per cent. of loading of the engines is unfortunately not given. The engine economy reported by Roberts seems extremely good in view of the fact that the engines are of but 400 h.p. capacity. They are of the Buckeye type.

TABLE VI.

RESULTS OF TESTS GIVING MAXIMUM AND AVERAGE LOADS, AND MAXIMUM VARIATIONS OF LOAD IN FIFTEEN MINUTES.

		April 17.		April 18.		April 19.	
		H.P.	K.W.	H.P.	K.W.	H.P.	K.W.
Maximum load recorded.........	Engines indicated	3020	2250	3020	2250	3380	2520
	Dynamos. delivered	2620	1950	2820	2100	3100	2315
Average load.....	Engines indicated	2140	1600	2060	1540	2465	1840
	Dynamos. delivered	1860	1390	1870	1385	2220	1660
Maximum variation of load recorded for 15 minutes ..	Engines: indicated	3020 2340	2250 1750	2550 1800	1900 1350	3020 2050	2250 1530
	Dynamos: delivered	2550 1840	1900 1375	2340 1700	1750 1275	2870 1540	2100 1150
Maximum variation as above in per cent.	Engines..........	29	29	41	41	47	47
	Dynamos........	35	35	37	37	83	83

FRICTION TESTS.

Table VIII. gives the results of a special friction test of Engine No. 2 made on the morning of the 19th, after all cars had ceased running. Ten readings were taken after the operators in every

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*Street Railway Jaurnal, September 6, 1902.

substation had been instructed to disconnect the direct current leads of the rotaries, leaving them running free. The power indicated then, included that used in engine friction, generator losses, transformer and transmission losses, and that required to run all the rotary converters in the system.

The operators were next telephoned to throw off the rotaries, leaving the transformers only on the line, and ten more readings were taken. The difference in the indicated power between these first two conditions is that required to run the rotaries.

The generator switches were then opened, and ten readings taken on " no load," with normal field excitation. The difference between the power indicated under conditions No. 2 and No. 3 is that lost in the transformers and in the high tension transmission lines.

TABLE VII.

ENGINE LOG.

ENGINE No. 1.	Cut in, 4.15 A. M., April 17.	Out, 1:30, April 18.	21¼ hours.
	Cut in, 4:30 A. M., April 19.	Out, 6:00 A. M., April 19.	3½ hours.
	Total, 24¾ hours.		
ENGINE No. 2.	Cut in, 5:00 A. M., April 17.	Out, 7·00 A.M., April 17.	2 hours.
	Cut in, 5.00 A. M., April 18.	Out, 1.30 A.M., April 19.	20½ hours.
	Cut in, 6.15 A. M., April 19.	Out, 1:30 A.M., April 20.	19¼ hours.
	Total, 41¾ hours.		
ENGINE No. 3.	Cut in, 7:15 A. M., April 17.	Out, 11:30 P. M., April 17.	16¼ hours.
	Cut in, 4:15 A. M., April 18.	Out, 11:45 P. M., April 18.	19½ hours.
	Cut in, 5·00 A. M., April 19.	Out, 12·15 A. M., April 20.	19¼ hours.
	Total, 55 hours.		

Next, the field circuit of the generator was opened, and the engine ran free, ten readings being taken under these conditions. The power shown by this final set of readings is that consumed in overcoming the friction of the generating unit, and may be considered constant at all loads. The difference in the power under conditions No. 3 and No. 4 gives the hysteresis and eddy current losses.

The engine and generator friction loss of 64.2 horse-power is only 3.2 per cent. of the maximum capacity of the engine and only 5 per cent. of the average power developed by the engine during the test. Including, as it does, the friction in both engine and generator, this is a low value.

GENERAL PLANT EFFICIENCY.

In summing up and determining the general plant efficiency a method has been resorted to for reconciling the recording wattmeter readings with the instantaneous readings which it is believed gives a correct adjustment between the indicated engine load and the generator load recorded by the integrating wattmeters. In Figs. 7, 8 and 9 the instantaneous i.h.p. and k.w. readings have been plotted against time and the ratio of the areas of these curves is proportional to the ratio of the total indicated power to the total power generated, on the assumption that variations in the load between plotted points follow the straight lines connecting the plotted points. As a matter of fact, during the 15 minute intervals between the plotted points of these curves, material variations take place in the load. These variations, which Figs. 7, 8 and 9 fail to record, are summed and included in the wattmeter readings. Consequently, to determine the correct value of the indicated power of the engines, for comparison with the total output of the station as recorded by the recording wattmeter, the total indicated power as determined from the areas of the i.h.p. curves of Figs. 7, 8 and 9, must be multiplied by the ratio of the k.w. hour outputs recorded by the recording wattmeter, to the areas of the k.w. curves of Figs. 7, 8 and 9. Following out this method, we find that the i.h.p. output as determined from the curve of Fig. 7 must be increased by 11.5 per cent. (see Item 11, Table 9) to be a true measure of the total indicated h.p. hours developed on that day. In the same manner an increase of 8.4 per cent. must be made for April 18 and of 6.9 per cent. for April 19th to bring the indicated h.p. hour values up to a point where they are correctly comparable with the k.w. hour output values determined from the recording wattmeters.

TABLE VIII.

SPECIAL TEST.

	H.P.		K.W.
Average power developed under conditions No. 1	341.4	or	254.5
" " " " " " 2	199.4	or	148.8
" " " " " " 3	100.5	or	74.8
" " " " " " 4	64.2	or	47.9
Power required to run the rotaries	142.0	or	105.9
Power lost in transformers and transmission	98.9	or	74.0
Power lost in hysteresis and eddy currents	36.3	or	26.9
Friction loss in engine and generator	64.2	or	47.9

Table IX. contains a tabulation of the results which show the thermal efficiency of the plant. From this table we find that the efficiency of the furnaces and boilers is 79.6 per cent., *i.e.*, 79.6 per cent. of the total heat in the coal as fired is delivered by the boilers to the engines in the steam. The average thermal efficiency of conversion between the boilers and the engine cylinders is 9.11 per cent., *i.e.*, 9.11 per cent. of all the heat delivered in steam by the boilers is converted into work in the cylinders of the main engines. This value of 9.11 per cent. credits against the engines the heat in the steam used in the auxiliaries. If we follow out the assumption that 15 per cent. of the steam delivered by the boilers is consumed by the auxiliaries, the thermal efficiency of the engines works out to be 10.7 per cent. The average thermal efficiency of the plant is 7.25 per cent. from the coal pile up to the engine cylinders and the average thermal efficiency of the plant from the coal-pile to the switchboard, *i.e.*, the ratio of the energy delivered by the generators to the total heat in the coal, is 6.39 per cent. Although it is frequently stated that the thermal efficiency of the steam engine at a maximum is about 25 per cent., it is improbable that any engine of this class working under these conditions will convert more than 12 per cent. of the heat of the steam into work. The thermal efficiency of 6.39 per cent. up to and including the switchboard shows high economy as compared with other stations of a similar character.

TABLE IX.

STATION EFFICIENCIES.

No.	Quantity.	April 17.	April 18.	April 19.	Total.
1	Coal burned, pounds..............	144,500	145,000	146,000	435,500
2	Water evap. from 11.45° C.........	1,229,700	1,244,400	1,244,400	3,717,500
3	Water evap. per lb. coal.	8.51	8.58	8.52	8.53
4	Equiv. evap. per lb. coal...........	10.21	10.30	10.22	10.24
5	EFFICIENCY FURNACE AND BOILER..	79.1	79.7	81.1	79.6
6	I.H.P. from area curve.............	51,300	48,000	55,000	153,820
7	THERMAL EFFICIENCY ENGINES.....	9.14	8.55	9.65	9.11
8	TOTAL THERMAL EFFICIENCY.......	7.23	6.82	7.82	7.25
9	K.W.H. from area curve...........	29,200	29,500	34,450	93,150
10	K.W.H. from wattmeter...........	33,000	32,200	36,700	101,900
11	Error (W.M. as standard)..........	11.5%	8.4%	6.9%	9.1%
12	Efficiency generating units, ratio areas........................	87.2	90.0	90.5	89.2
13	Efficiency generating units, average instantaneous efficiencies...	86.1	89.4	89.1	88.2
14	TOTAL THERMAL EFFICIENCY.......	6.23	6.08	6.96	6.39

The total thremal efficiency of the Harrison Street station of the Chicago Edison Company has been estimated to be 4.5 per cent., while the thermal efficiency of the generating station of the

Blue Island, Chicago Storage Battery Road was found to be 5.5 per cent.*

Items 12 and 13 of Table IX. give the efficiency of the generating units, *i.e.*, the ratio of the delivered electric power to the indicated power of the engines. Item 12 is the ratio of the k.w. and i.h.p. areas of the curves of Figs. 7, 8 and 9, while Item 13 is the average of the instantaneous ratios of the delivered electrical power to the indicated mechanical power. The two methods give—as they should—substantially the same values and are a check one upon the other

The maximum power indicated by the engines is 3,380. This load came on April 19th at 5.45 P. M. The maximum variation in the load in fifteen minutes also occurred on April 19th, but between 1.45 and 2 P. M., when the load changed from 3,020 to 2,050 h.p. This is a variation of 47 per cent. in the indicated power of the engines. The variation in the load during this time, as shown by the electrical instruments, is 83 per cent., which indicates that the engine fly wheels materially diminished the strain on the engine cylinders by bringing their stored energy into play. The greatest average load occurred on April 19th, and was 2,465 h.p.

TABLE X.

COSTS.

	April 17.	April 18.	April 19.	Total.
Cost coal per K.W.H.	$.00295	$.00304	$.00269	$.00288
K.W.H. per pound coal	.229	.222	.251	.234
Cost coal to evaporate 1,000 pounds of water from and at 212°	$.0655	$.0651	$.0657	$.0654

The Anderson power plant of the Union Traction Company uses Indiana block coal in developing power. It is delivered at a cost of $1.35 per ton. On the basis of this figure, as shown in Table 10, the cost of developing a k.w. hour is $.0028. The cost of developing a k.w. hour may be taken as the final estimate of the efficiency of any station, as the aim and end is to develop as much power as possible per unit of cost. The fuel cost to develop a k.w. hour output varies materially in different stations. In the *Street Railway Review* articles already referred to, the cost in fuel

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***Street Railway Review*, February 15, 1898. Test of the Chicago S. B. Road.

per k.w. hour varies from $.00246 to $.01016. The average of the best results, those reported in the *Street Railway Review* of July 15, 1900, is $.0045, an amount considerably larger than the cost economy shown by the Anderson station. Tests of the Oshkosh Street Railway plant, already referred to, show a k.w. hour to be developed at a fuel cost of $.01009. The test of the Chicago Storage Battery Road shows the fuel cost per net k.w. hour output to be $.00611, and the Chicago Edison is reported to develop a k.w. hour output at a cost of $.003. These figures are sufficient to show that the fuel cost economy of the Anderson station is extremely good and that the company is probably developing power at as low a figure as is possible under ordinary conditions of electric railway central station power development.

The thanks of the authors are especially due to Mr. A. S. Ritchie, electrical engineer, and Mr. A. J. Black, mechanical engineer, of the Union Traction Company, for their great assistance in facilitating all the arrangements for the tests and in materially promoting their successful outcome.

Discussion.

Professor Goldsborough:—I have here another Chart A, which shows the ultimate efficiency of the plant in terms of the total power delivered to the cars. We see, then, that the station

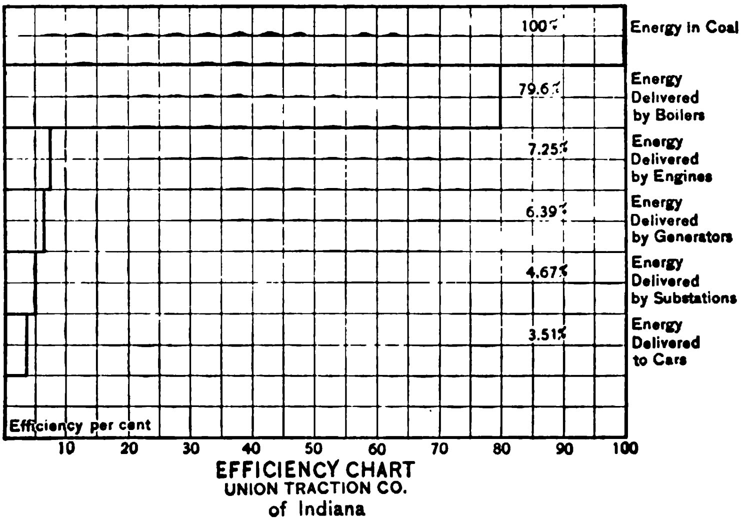

Chart A—Part 1

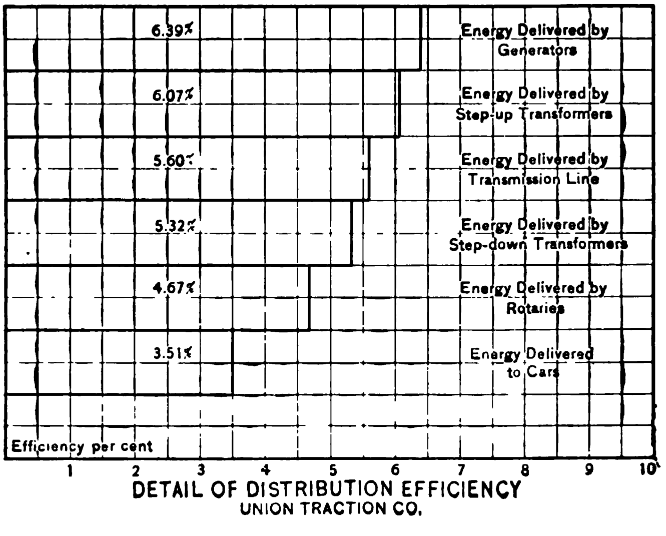

Chart A—Part 2.

delivers to the line 6.39 per cent. of the total energy of the coal, and there is 3.51 per cent. only of the total energy of the coal that ever gets to the cars.

Mr. Gerry:—I would like to ask a question in reference to the figures given; the speaker states the efficiency of generation as 12.63 per cent., and I understood him to say the total efficiency was 3.65 per cent. To what does the last figure apply? Where was the power delivered at the efficiency stated?

Professor Goldsborough:—The last figure applies to the power which was delivered to the cars, and this power was determined by having indicating wattmeters on all of the cars, so that we got the actual power delivered to the cars from the generating station; to the car, not to the axle.

Mr. Gerry:—That represents about 50 per cent. efficiency between the station, and the power delivered to the car?

Professor Goldsborough:—Yes; the efficiency of the high-tension transmission system is about 74 per cent. That is, including the raising transformers, high-tension wires, depressing transformers, and the rotaries; and about 75 per cent. for the low-tension network. So that you get a loss, as you suggest, of about 55 per cent. all told.

Mr. Gerry:—Yes; less than 50 per cent. That is rather large, and it would be interesting to know the result if everything were included between the electrical output of the station, and the mechanical output of the cars. It would reduce the total efficiency of the plant at the car-axle by certainly 25 per cent. or 30 per cent., making the total efficiency of the installation around 2½ per cent.

Professor Goldsborough:—I think that is a fair assumption. Now, we must remember that in this particular system the cost of copper has been made as low as possible. Power is developed so cheaply that power is about the cheapest thing they have. In other words, one passenger per car comes pretty near paying the cost of the power used by that car from Indianapolis to Muncie, and they only charge one cent a mile.

Mr. Gerry:—Then this plant is not presented as an example of a high efficiency, or even of average efficiency, as far as power is concerned. The point I was intending to bring out was, that the efficiency of transmission was low, very low. I have not read the Professor's paper, and may not understand the situation fully, but I understood this plant was presented as an example of one of fair, or high efficiency, but we have here in the transmission an indication of a very low efficiency.

Professor Goldsborough:—I look at the matter in this way —we have here a series of tests upon a very highly efficient interurban property. But how are we to gauge or determine its efficiency? Are we to gauge it on the basis of efficiency in terms of power conversion or on the basis of efficiency in terms of its paying capacity? Now, it has a very high financial efficiency; it makes a good return on the investment. Every element which enters into the station is sufficiently large and properly installed to meet all emergencies. It is a safe property so far as its ability to operate continuously is concerned. When it comes to determining whether you shall put more or less copper into the distributing system, you have to go right about finding out what coal costs you, what the interest cost on your investment is, and what the operating cost of your system is. These elements must be made to bear a proper relation to each other. You should not put capital into large feeders and appliances to make the efficiency of distribution high when by so doing you create an interest cost greater than the value of the power thereby saved. I think that we should consider this plant as being a measure of what engineers, after careful analysis of the problem, have determined upon as most fit to promote the best economy in the operation of an interurban system. And it is just as vital for us to know that we should have a 50 per cent distribution to obtain this economy as it would be for us to know that we must have a 99 per cent. efficiency to obtain it.

Mr. Gerry:—I think Professor Goldsborough does not meet my point exactly. I do not know of any reason why you should put in a high efficiency station to make cheaper power, and then put in a low efficiency distributing system so as to waste the power afterwards. If you can produce power cheaply, and want to keep down the first cost of the station, put in a moderate class system all the way through. I desired to find out whether this was a high-class station and low-class distribution, and if so, why?

Professor Goldsborough:—I think the matter can be answered very well in this way. We are confronted by a problem, we are required to deliver a certain minimum amount of power to certain cars continuously and as cheaply as possible. Now if we put in a low-class generating station, low-class transformers, low-class rotaries, low-class storage batteries, we will not be able to meet the conditions. Now if we have high-class generators, transformers, rotaries, and all intermediate machinery, we are in a condition to render reliable service; this must be done anyway regardless of the copper used Any man who builds a station and puts in a second class engine, is doing himself and all of the people depending upon him an injustice. He must have the best there is in that particular element to secure the permanency of the plant. Now, when it comes to the question as to where his losses shall take place—he can get a good engine for the same money that he would pay for a poor one; he can get a good dynamo on about the same basis; and there is no excuse for putting in bad machinery In the case of his copper conductors however, it is another matter Copper is copper, much or little, and in it should occur " the loss " in interurban work if the low cost of fuel warrants any excessive power loss at all As long as conductors are strong enough and do not heat excessively, they are reliable elements in the system;

and whether they are small or large is unimportant so long as their cost is properly adjusted to the earning capacity of the plant as a whole. They are now using 16,000 volts. In the system they are putting into Logansport they are going to use 32,000. Maybe some day instead of operating the cars with direct current at 500 volts, they will operate with alternating current at 10,000. They may be able to operate a system of twice the size with the same generating plant. That is one of the things they are thinking about, to see if this plant which is now able to operate only 100 miles of road cannot be made to operate 200 miles, not by increasing the total cross-section of the copper but by decreasing the total cross-section of the copper and increasing the depression

Mr. Gerry:—Then the high efficiency is a matter for the future. I hope the Professor will not understand me as advocating the undesirable types of machinery which he indicates. There is a real difference, however, between high and low-efficiency machinery, not only in its economy, but in the first cost; in other words, you can obtain very excellent steam and other machinery if you are willing to content yourself with a little lower efficiency, and such machinery is really excellent for service, and there are many places where it should go in. It will give good results practical results, but still, it is not the highest efficiency machinery. In fact, the highest-efficiency machinery does not always give the best operating results; but where the costs of labor and fuel are high, then efficiency becomes of importance, and we go to the extremes of cost and refinement to obtain the best results in that direction. I was simply trying to settle the question whether this was a case for such refinements, and if so, why the efficiency was afterwards sacrificed in the transmission system.

Mr. Stott:—The ultimate object in any power plant, it seems to me, is to place the kilowatt hour on the receiving apparatus at a minimum cost, and there is no other object in a power plant, so far as I know You have to take into consideration, first, the cost of coal. If the coal is going to be a very high item, you must put in an extremely efficient plant, and put in all the accessories, such as economizers, feed-water heaters, etc. If your coal is a very cheap item, you can afford to sacrifice a great deal and reduce the interest charges on the plant. But in the end you must consider the whole problem; viz., what you expect to deliver the kilowatt hour at the receiving apparatus for. Now, in this paper we have not been given the total cost of the power delivered, as I understand it. I may not have read the paper carefully enough. This is only the fuel cost that is given, is that right? The total cost as it is delivered at the car is the real test. While the cost as shown here in coal is extremely low, yet it may be a great deal higher when delivered at the car than in a great many other plants. In New York the proportion that the cost of coal bears to the total cost is about 70 per cent.

There of course we must have an extremely efficient distributing system as well as power plant, and every thing you can do to reduce the amount of coal is justifiable. The efficiency from the generator to the engine—this constant which is introduced by a comparison of the various indicated wattmeter curves with recorded wattmeter curves, is something entirely new, and I think makes comparison rather unfair to plants whose efficiency has been calculated merely upon the basis of indicated horse-power to kilowatt output; and to make the comparison perfectly fair other plants should have this factor introduced as well as a factor covering the difference in load-factor. If Professor Goldsborough can give any information upon the question of total cost delivered at the car, I think it will make the paper a great deal more complete.

Mr. Dunn:—It is a fact that " cost " is one of the most loosely used terms in electrical nomenclature. When I see it I hesitate to pay attention to the figures given because there is so seldom any definition of what they include. I wish it were possible for us to get the idea that we should never use the word " cost " without saying what cost we mean. I wish also that it were possible that costs presented before the Institute, for statistics should never be given unless they included interest charges, taxes, depreciations, charges for sinking funds, and every other item, so that we should have before us when we were considering cost figures everything except dividends. Our statistics on the cost of power are of little use because of this lack of definiteness in specifying what we include when we say " cost."

Mr. Wells:—I notice that Professor Goldsborough's estimate of moisture in the coal was 6 per cent. I would say that in 77 analyses made on eight different grades of bituminous coal, the moisture varied from 1.15 to 5.25, or an average of about 3 per cent. for all the different grades, and that the calorific value of these coals varied from 12,967 B.T.U. to 14,041 B.T.U.

Mr. Lincoln:—The question which Mr. Gerry raised in regard to Professor Goldsborough's paper seems to be simply a question of Kelvin's law. He can develop his power for a certain amount at the station, and it is a question of a well-known law how much of that shall be lost in his line. If his power is cheap he can afford to lose more power in his line than if the power costs more. It is for the engineer to determine whether he shall put money or energy into his line.

Professor Goldsborough:—The reason that no more figures are given than have been given of cost has been stated by the other speakers. We took that matter up, and had it been carried out to the point that we wished there would not have been anything else to say. The whole story would have been told. Everybody who has any idea of buying or selling stock would have been given ideas regarding the plant which possibly the directors would not care that they should have. I have made a number of tests on plants and have worked down through the financial side as well as the engineering side of the problems, but I have never yet had the consent of directors to my publishing that part of a report which deals with the finances of the plant, further than the part that covers the ordinary operating expenses. I have not gone further than I have for the reason that when I give you the cost of a kilowatt-hour in terms of the cost of the coal, I give you something that is perfectly definite; everybody knows what I mean. If I should give you other figures you would immediately want to know what they included. I may say, however, that the cost of manufacturing power in this plant is about one-half cent a kilowatt-hour. This figure does not include any of the items which Mr. Dunn has said ought to be included.

As regards this particular plant, you will notice, by the floor plan of the building, that room is allowed for two or three more units, although objection was made to the fact that I pointed to the future in discussing why good machinery was put into this plant. It is expected that the plant is not to be a present-day matter. It is in a place where coal is cheap, it is in a region where the population is well distributed and is large, and where people are in the habit of traveling. The system is expected to grow; and already it is double the size it was when this test was made.

Now, as regards moisture in the coal. The coal in this particular station is kept over the boilers. A sufficient supply of coal is placed there so that the coal becomes pretty thoroughly dried out before it is fed into the furnaces. As the station is ordinarily operated, the coal is never handled by hand; when received it is dumped into the station, conveyors carry it around, ashes are taken out, and you wouldn't know there was any coal except that you see the little that runs out from the chutes into the furnaces. There are only two men in the boiler room of the station.

We took samples of coal regularly by the most approved method, separating it all out, etc., and then put it in cans and put tops on these cans. But it so happened that we could not get the cans soldered up for three or four hours, and during that time the coal was subjected to different conditions of moisture in the atmosphere. When we tested our coal finally, by chemical analysis, etc., we found we couldn't rely upon the results. We had to go back to the point of approximating, not because our work was inaccurate, but because we did not believe it represented all the conditions of operation in the plant. We took six per cent. as the result of a general inspection and a review of other printed results showing the use of the same coal.

PRESIDENT SCOTT:—We will now turn to another subject, " The Electrical Equipment of a Gold Dredge," by R. L. Montagu.

Paper read by Mr. Gerry.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 2, 1903,

THE ELECTRICAL EQUIPMENT OF A GOLD DREDGE.

BY RALPH L. MONTAGU.

Before describing the electrical equipment, it would be well, perhaps, to say a few words relating to the use and object of a gold dredge.

The occurrence of gold in deposits of gravel is caused by the action of some river or glacier which in its course has broken up and carried along in the form of gravel the rock that formed the boundary of its channel.

When gold-bearing veins exist in this rock, the gold, in the course of time, becomes freed from its surrounding ore, and is together with the gravel already formed deposited at some point where the velocity of the water ceases to be high enough to keep the gravel in motion.

Placer mining is the name by which the process of extracting the gold thus deposited from its surrounding gravel, is known. Briefly, it consists of feeding gravel and water into a rectangular trough (sluice box), set on a grade, on the bottom of which depressions or hollow spaces (riffles) are provided. The gold, owing to its high specific gravity, settles in these depressions while the gravel is carried on down the sluice and dumped at the end.

To accomplish this process on a large scale, there must be sufficient grade to the deposit of gravel and its underlying bed rock to prevent the worked-out gravel (tailings) from interfering with the excavating operations which are feeding the gravel into the sluice.

Where the natural grade is not sufficient for this purpose, a grade must be produced by artificial means. Until dredging was applied for this purpose the method known as hydraulic mining was used. It consisted of sinking a pit to bed rock, the gravel being lifted into a sluice box supported on a trestle by an hydraulic elevator. The most common way of breaking down the banks of gravel was by the use of a stream of water under a high head (hydraulic giant) directed against the face of the bank. But in localities where sufficient water could not be obtained for hydraulic mining, except at a prohibitive expense, the deposits have not been considered of any value until the advent of the gold dredge. Furthermore, where sufficient water was available to work the deposit by the hydraulic method, the same water if applied to turbines for the generation of electric power to be used to drive dredges, would handle from two to two and a half times more gravel.

Fig. 1 gives in outline a type of gold dredge. The excavating is done by the endless chain of buckets, which revolving around the upper tumbler, dumps the gravel into a revolving screen (termed a *grizzly*). Jets of water play on the gravel and thoroughly wash it; the fine gravel and gold fall through the openings in the grizzly into a sump, from whence it is picked up together with sufficient water and elevated into the sluice box. The coarse gravel, large stones, etc., are allowed to fall overboard, being of no value. The gold, as already described, is recovered in the riffles forming the bottom of the sluice; the washed gravel carrying practically no values, falls over the lower end of the sluice and fills up the cut that was previously made by the dredge. The dredge is held in position by the anchor or spud at the stern, and side lines from the bow permit the buckets to be freed across the face of the cut. There are two spuds on a dredge, one is used for holding the dredge and the other is used when a cut is completed and it becomes necessary to step the dredge ahead. With this type of dredge it is possible to handle .85 cubic yards of gravel per h.p. hour delivered on board.

The various pieces of machinery, together with their respective motors, may be summarized as follows:

The endless chain of buckets driven by a variable speed reversible motor; the revolving screen, together with a small pump for furnishing the jets of water, driven by a constant speed motor; the large centrifugal pump for elevating water and gravel into the sluice, driven by a constant speed motor; the winch which revolves drums to which are attached the side lines, lines for

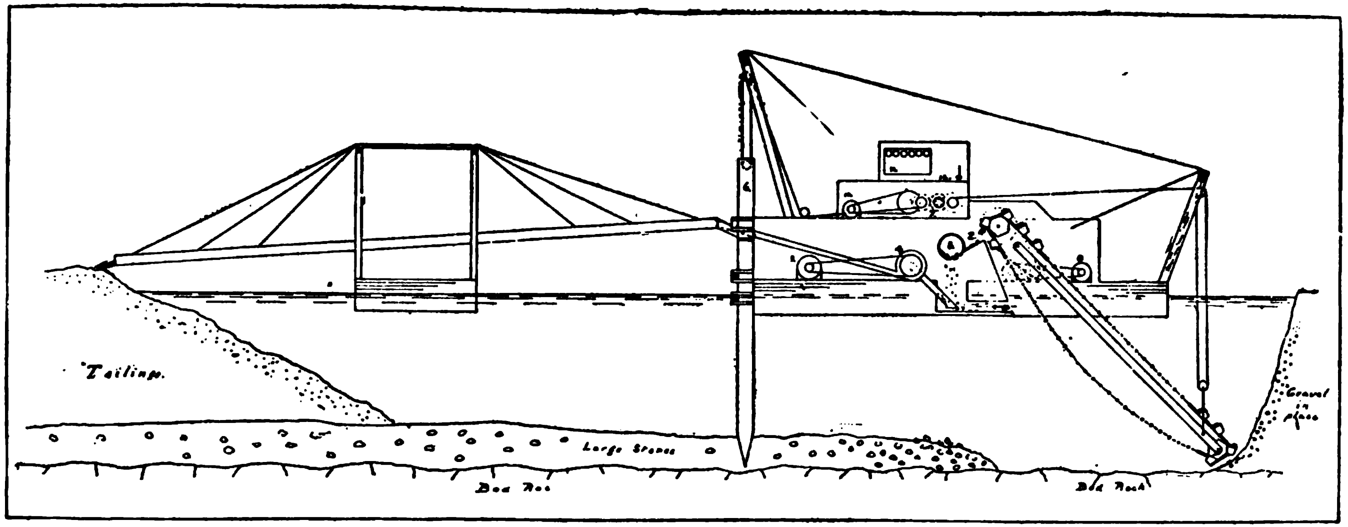

FIG. 1.

1 Buckets excavating gravel.
2 Buckets dumping gravel.
3 Revolving screen
4 Centrifugal pump.
5. Sluice box.
6. Spud or anchor.
7. Winch.
8. Bucket driver motor var. speed.
9. Pump driver motor const. speed.
10. Winch motor var. speed.
11. Switchboard.
12. Pilot house and operating trusses.

hoisting bucket chain and lines for hoisting spuds, is driven by a variable speed reversible motor. The first dredge that made a commercial success as a placer mining machine in the United States was installed at Bannack, Mont., in 1895. The property owned by the company (The Gold Dredging Co.) included a water-right and ditch, which if extended about two miles would give a head of 340 feet. As the water at this head would give sufficient power to drive a dredge it was decided to use electric power in preference to steam. The fuel cost was for wood $4.50 per cord and for coal $12.00 per ton. The writer installed the electric equipment, which consisted of a 100 k.w., 500 volts d.c. generator, running at 650 r.p.m., and four street railway motors.

The generator was direct connected to a 26″ Pelton water wheel, by means of an insulated coupling. The power was transmitted over 000 stranded conductors, triple braid weather proof, from the pole line on shore to a reel on the dredge. Two of the motors were mounted on wooden bases sliding on rails and had overhung pulleys in place of the pinions; they were used to operate the winch. One motor drove the drums for hoisting the spuds and the other motor operated the balance of the winch. The controllers were of the rheostatic type. The other two motors were geared to counter-shafts having pulleys mounted on them, the whole mounted on wooden bases, and they were controlled by d.p. switches and starting resistances of iron wire; one of these motors was supplied with a d.p. reversing switch. This motor had to drive (1) the endless chain of excavating buckets, (2) the revolving screen and (3) a secondary chain of buckets, which elevated the screened gravel into the sluice. The other motor drove a 10″ centrifugal pump that supplied water to the sluice box.

No trouble was encountered with the generating end of the plant, with the exception of a little difficulty owing to a mistake in the water-wheel design, which necessitated the lengthening of the water-wheel shaft, so as to allow sufficient clearance between wheel and housing to permit the dead water to fall away from the wheel; but on the dredge considerable trouble was experienced in operating the motors. Both these motors were overloaded and their design in general left plenty of margin for improvement.

During the first season (1895) very little excavating was done, but enough work was done to demonstrate that these motors would not give satisfaction if the load was not lightened on them:

accordingly, during the interval between the seasons of 1895 and 1896, the motor driving the 10″ centrifugal pump was replaced by a shunt wound motor and the load of the other railway motor was divided between it and the motor taken off the pump One motor drove the bucket chain (1) and the other, the grizzly and secondary chain. Mechanical changes were effected at the same time, which permitted the almost continuous operation of the dredge during the season of 1896. As the motors now were running on an average of 23 hours per day, there were plenty of opportunities for the weak spots to develop. The motor driving the bucket chain (excavating) burnt out an armature on an average every thirty days. The ends of the commutators next to the bearing on these motors were constantly getting grounded, the brushholders were overheated and brushholder springs lost their vitality. By keeping two or three extra armatures on hand no time was lost on armature account; but on one occasion the lower field coil of the motor that drove the grizzly became badly grounded, and short-circuited. As we had no spare field coils on hand I unwound the coil, rewinding the wire on a barrel, and after painting the interior of the field bobbin with insulating paint, I rewound the coil with the old wire, painting the wire as it was laid on. From my recollection, I should say the wire was about 000 solid, and anybody who has had to rewind a magnet coil with previously used wire of this size and with practicaly no appliances, such as sheaves for wire to run over, need not be told that I did not get back on the field-bobbin all the wire that came off; however, I got back enough to answer the purpose and within 10 hours from the time of the accident the dredge was in operation again, and the motor lasted to the end of that season.

During the winter of 1896–1897 it was decided to discontinue the use of the secondary chain of buckets for elevating the screened gravel into the sluice, and to use a centrifugal pump of sufficient size to lift this gravel and the necessary water for sluicing it. The new arrangement presented an outline similar to that in Fig. 1.

The experiences met with in this the first successful application of a dredge to placer mining in America have been described at considerable length, because this plant was the forerunner of numerous others in localities throughout the mining districts of North and South America, which have created a new demand for labor and opened a field for the investment of millions of dollars.[1]

I will now endeavor to describe the nature of the loads on the various motors. That on the motor that drives the bucket chain is a peculiar one; it may be described as a combination of an elevator load and a street car load, but with many less stops and no particular need for very rapid acceleration. When beginning a cut at the surface, the incline up which the buckets travel may be only 20° from the horizontal, the soil as a rule is very loose and the starting torque is, comparatively speaking, nominal. The motor has only to overcome the inertia due to the mass and weight of bucket chain, viz., from 250 to 400 lbs. per foot of length. As the buckets become loaded with gravel, the load increases. The speed of the bucket chain at the top of the cut can be as high as 60 feet per minute with safety. This load is similar to an elevator load and is steady; the only fluctuations being caused by a bucket as it revolves round the lower tumbler, taking an extra large bite out of the gravel or missing the gravel and merely bailing water. As the depth of the cut increases, the load increases on the motor because the angle between incline of chain and horizon is greater; and if a series wound d.c. motor is used some resistance should be cut out, if it is still safe to maintain the high speed. When a certain depth is reached and the gravel becomes coarser, is packed harder and large boulders are liable to be met with, the speed should be reduced by cutting in resistance; finally, when close to bed-rock, the speed should be still further reduced; the buckets should not now exceed a speed of 40 feet a minute; and in actually scraping bed-rock the speed should be still further reduced. The buckets are now nearly empty of gravel; the incline is about 45° with the horizon, and it will be necessary to cut in all available resistance into the circuit of a d.c. series or into the secondary of an induction motor. The construction of this resistance should be such as to permit its being kept continuously in the circuit, as in some fields it is necessary to keep up the scraping of bed rock for several hours because the majority of the gold values are obtained on or near bed rock.

During this, the most important part of the excavation of a cut, the motor is running with a low efficiency; and it

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[1] At this point (Oroville, Cal.) there are in operation and building over 20 dredges; each dredge has cost at least $50,000; and the ground to be mined previously worth from $2 to $10 per acre, sells now as high as $1,500 per acre.

may be asked why a two-speed gearing should not be introduced so that the motor would operate efficiently at the low bucket speed. In one case, to my knowledge, a two-speed gear was tried, but finally discarded, because it did not give such general satisfaction as the arrangement at present in almost universal use, viz., a d.c. series-wound motor with rheostatic control or an induction motor with a variable resistance in secondary or rotor circuit.

I have not yet mentioned the condition when the most severe load is thrown on the motor, that is when the motor is stalled. At some point in the train of gears that reduces the high speed of the motor to the low speed of the top or driving tumbler (2.75 – 5 r.p.m.), an adjustable slipping-friction is placed and set so that it will slip before the circuit-breaker or fuses open the motor circuit. The buckets may encounter an extra large boulder, a submerged timber or stump or the bank may cave down and completely bury them. Let us suppose the buckets are running at a speed of 45 feet per minute when an obstruction is met that causes the friction to slip. The motor is stopped and when it has come to rest it should be allowed to run back so as to let a little slack into the bucket chain. Sometimes it is necessary to reverse the bucket chain one bucket or link length. On restarting the motor the obstruction may be removed, sometimes, however, it is necessary to stop and start a number of times before this is accomplished; it may be necessary to tighten the friction or hold the circuit breaker from opening, but whatever the nature of the obstruction, it must be overcome because if boulders are not dug out and disposed of they will be liable to form an effective barrier between the buckets and bed-rock, which will mean that a large proportion of the gold contained in the cut is not recovered.

Sometimes it is necessary to stop the buckets, which may be running at full speed, in two or three seconds of time; the only way to do this is to reverse the motor. Therefore, it will be seen that the motor that drives the bucket-chain should be capable of withstanding considerable strains, both mechanical and electrical. I have seen a d.c. series wound motor (500 v.) the normal current of which was 40–60 amperes, take over 200 amperes, while picking up a particularly large boulder; and a 3-phase, 1000 v. induction motor, normal load 25 amps. per phase with secondary short-circuited, has taken

95 amps. per phase, while the buckets were being released from an extra large cave-down of gravel.

The periods of these abnormal loads are limited, rarely exceeding a full minute. While not attempting to deduce an exact formula for determining the necessary rated h.p. of a motor for this class of work, I will state that calculations can be based on the fact that a 50 h.p. motor should be installed to drive a chain composed of alternate buckets and links, the bucket capacity being 5 cubic feet each, built of good mechanical proportions and capable of reaching a maximum depth below water level of 35 feet, the top or driving tumbler being suspended about 14 feet above water level. In actual work the incline up which the buckets travel does not exceed an angle of 45° with the horizon.

Passing on to the motor that drives the grizzly and small centrifugal pump, very little need be said about it; the load and speed are constant and in starting the load is light as the centrifugal pump does not begin to pick up water until nearly full-speed is reached. A shunt d.c. or induction motor, squirrel cage type, of 30 h.p. is generally used for this load, *i.e.*, where the grizzly and pump are proportioned to screen and wash the gravel excavated by the 5 foot bucket chain.

The same remarks about load and power required to start apply to the motor that drives the large (12″) centrifugal pump that elevates water and gravel into the sluice; the h.p. of the motor can be found from the following formula:

$$\text{h.p. of motor} = \frac{(\text{diam. of discharge in inches})^2 \times \text{feet lift}}{2 \times 20}$$

A little difficulty may be experienced in finding the exact diameter of motor pulley. There is a certain critical speed at which to run a centrifugal pump that lifts water and gravel; a reduction of 10 per cent. below this speed reduces the velocity of the water to a point where it is unable to pick up gravel; 10 per cent. above the critical speed calls for an increase of power out of all proportion to the increase of speed of the pump, besides which the resultant velocity of the water in the sluice-box may be so high as to prevent the gold from being deposited in the riffles.

There are some peculiar facts concerning the operation of centrifugal pumps by constant speed motors. If such a centrifugal pump is lifting water to a certain height and the motor is fully loaded, a reduction of the head increases the load on the motor and *vice versa.* This statement may seem to be contrary to all laws regarding the conservation of energy; but the peripheral speed of a centrifugal pump is in proportion to the square-root of the height to which the water has to be lifted[1]; furthermore, the volume of water lifted is not in direct proportion to the speed. If x be the speed of a pump (running efficiently) and y = power used to elevate 1000 gallons at any head; if x is reduced to $x/2$, $y = 0$ (not taking into consideration the losses due to friction), and no water is moved. When the speed is increased above x, the amount of water lifted does not keep up in proportion to increased speed. There is more slip in the water moved by the runner or piston and the efficiency begins to fall off enormously; therefore, if we consider the original statement, we see that with a motor fully loaded and pump running at an efficient speed for a head of y feet, reducing y while moving more water, we do so at a very much lower efficiency and consequently overload the motor, provided the speed remains nearly constant.

The last motor to be considered is that which drives the winch used for swinging the dredge, hoisting bucket-chain, etc. The heaviest load this motor has is when the bucket-chain is being raised, the nature of which is similar to that thrown on an elevator motor. In raising the spuds or anchors, there is always some slack in the lines and full torque is not required in starting, In pulling on the side lines very little power is called for, but the speed variations required are beyond the scope of any motor. For instance, in digging off the top soil, the speed of the buckets across the face of the cut may be 20 feet a minute or more; when bed rock is reached, the speed may be as low as 5 feet a minute. When moving ahead and the buckets are not touching the gravel, the speed should be as high as possible, viz., 100 feet a minute or more. In general, the motor is geared to the winch, so as to produce the maximum speed, and the variations are produced by constantly starting and stopping the flow of current to the motor; this may seem to be hard on the controller, but the modern types of controller seem to stand this work remarkably well.

In some more recent winches a two-speed gearing has been adopted and this makes it easier for the controller. The only operation that it is necessary to consider when determining the maximum h.p. of the winch-motor is the hoisting of the bucket

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[1] The most efficient or critical peripheral speed of centrifugal pump in feet per minute

$$= \sqrt{\text{head in feet}} \times 8 \times 60$$

chain and the speed at which it is to be hoisted. All other loads that may be thrown on this motor are less than this load.

The current is taken aboard a dredge nowadays by means of an armored cable attached to a temporary pole line on shore; the slack cable is coiled up on the bank and as long as no heavy traffic passes over it and it is not covered up by the tailings, no trouble need be expected.

At Bannack, Mont., the writer designed a reel (Fig. 2) that was placed on the upper deck and the wires (000 stranded weather-proof insulation) ran over hard-wood sheaves and then swung onto the pole line. This class of wire had to be kept out of the water and off the ground. The object of the reel was to make it possible to take up slack or pay it out without stopping the operation of the dredge. This reel was exposed to the weather, but no leakage was ever apparent.

Where the current is brought aboard at moderately high voltages and it is necessary to use step-down transformers, these should on no account be anywhere except in a special deck house on the upper deck. The low voltage secondaries should be led to the pilot house, where a switchboard should be located, having a separate panel for each motor. On these panels there should be an ammeter s.p. switch and fuses or circuit-breakers, also a name plate designating the motor circuit to which these devices belong. The panel that has the main switch on it should have a voltmeter and v.m. switch, also the primary switch and fuses for the light transformer. On the light circuit there should be a voltmeter and the terminal board of a regulating device for raising or lowering the voltage of the light circuits. The individual light circuit switches should be named thus: " Port bow lights," " Starboard bow lights," etc.

The voltage of the motors should not exceed 400 a.c. or 500 d.c. There is no advantage to be gained in high voltage, as the leads from switchboard to motor never exceed 100 feet in length. The controllers for the bucket-drive motor and winch motor are located in the pilot house; the auto-starters for the other motors should be placed near the motors and the machinery they control. There should also be a complete system of push buttons and signal bells. Incandescent lamps are used almost exclusively; arc lamps give trouble owing to the constant vibration of the dredge. Fig. 3 is a diagram of the wiring of a dredge where the current was brought aboard at 1000 v. The power company supplied transformers for motors of 30 h.p. and

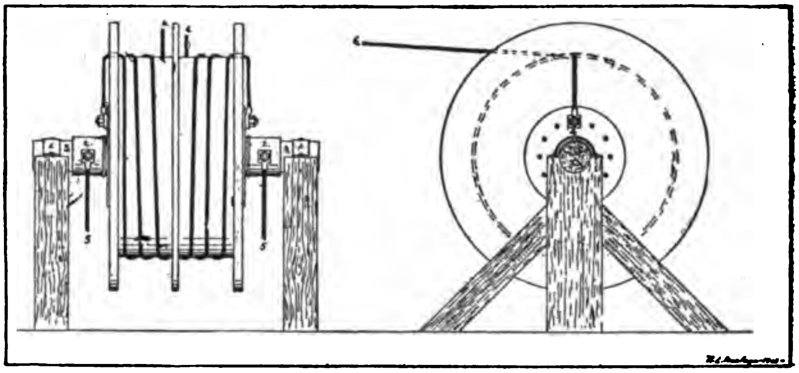

Fig. 2.

1. Strap to hold shaft.
2. Insulated sleeve.
3. Hard wood shaft (does not revolve.)
4. Insulated hub.
5. Wires to center of dist.
6. Wires to pole line as shown.

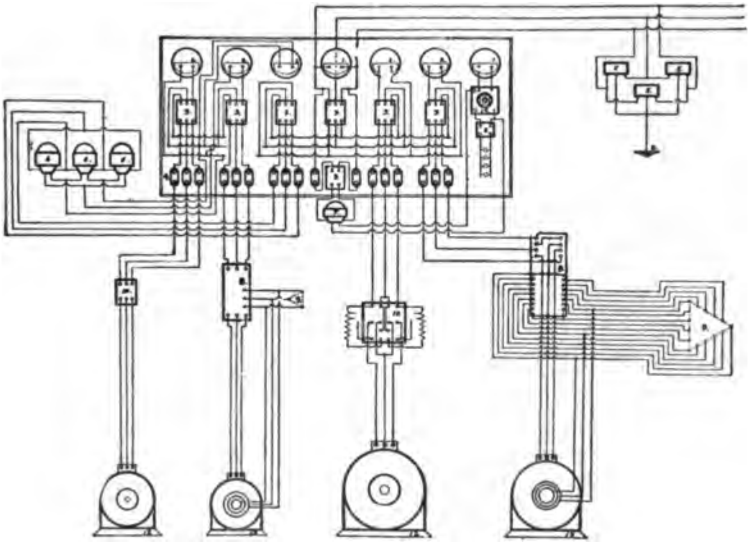

Fig. 3.

1. Voltmeters.
2. Ammeters.
3. Switches.
4. Fuse Blocks
5. Lightning arresters.
6. Transformers, 1000–400.
7. Transformers, 1000–110.
8. Controllers for var. speed motors.
9. Resistance.
10. Auto starter.
11. Ground connection.
12. Const speed motor.
13. Var speed motors.
14. Regulator for lamp circuits

less, which accounts for the fact of having motors of different voltage on board.

In determining the size of a power plant to supply a dredge or dredges, for every dredge similar to Fig. 1, the general dimensions of which may be described as being a 5-foot open-connected chain-dredge capable of excavating to a depth of 35 feet, with a 12 inch centrifugal pump for elevating purposes, 135 k.w. should be available at the bus-bars on board the dredge for 24 hours per day for d.c. plants, or 170 k.v.a. at .80 power factor where a.c. induction motors are used. The current is taken aboard in some places at 4000 volts. I believe about 5000 volts will be the limit for a few years anyway. The motors and resistances should be such that they will be able to run continuously, without the least danger of overheating. The average running time on the Bannack dredge was 23½ hours out of 24. In localities where the mining season is short, owing to severe winters, the usual practice is to run every day and night, Sundays and holidays included, the machinery being overhauled during the winter months.

The mechanical end of the plant causes quite as many shut-downs as are desirable and there should be absolutely no loss of time on account of defective electrical apparatus; therefore everything connected with the electrical part of the machinery on the dredge should be as near " fool-proof " as possible.

The ambition of every manager of a dredge is to keep the machinery at work all the time. When we realize that in some fields the possible mining season only lasts 150 days in the year, the value of every minute during this time becomes apparent to the most casual observer. As a general rule, these localities are a long way from a repair shop or supply house and the financial loss entailed by a burnt-out machine under these conditions is many times the value of the defective apparatus.

I do not suppose that even one per cent. of the dredging ground in existence is at present being mined; the process is still in its experimental stage. Although good results have been obtained so far, there is no doubt but that more advanced methods, both mechanical and electrical, will be discovered in the future to increase the efficiency of a process which is adding to the wealth of the world gold that would otherwise have remained in the ground where nature had placed it, viz.,—gold-dredging.

DISCUSSION.

PRESIDENT SCOTT:—The management of the Louisiana Purchase Exposition has appointed a general advisory committee on Electrical Congress. At the head of that committee is Professor Elihu Thomson and Doctor Kennelly is secretary. A meeting of the committee was held yesterday afternoon for preliminary work, and we should be pleased now to have a statement from Doctor Kennelly with respect to the work which is under way.

DOCTOR KENNELLY:—As stated by the President, a preliminary meeting of the advisory committee was held yesterday. It was unanimously voted at the meeting that an International Electrical Congress should be held at St. Louis next year in conjunction with the St. Louis International Exposition. It was also the opinion of the advisory committee that delegates from foreign countries should be invited by the United States Government to attend the International Electrical Congress, as at the Chicago World's Fair Congress in 1893, and as at the International Paris Congress of 1900, for the purpose of debating and fixing any questions which might naturally call for the attention of such a Congress. The further scope and purposes of the proposed Congress were not entered into. They were left for consideration at some future time.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, at Niagara Falls. N. Y., July 2d, 1903.

THE LEGALIZED STANDARD OF ELECTROMOTIVE FORCE.

BY HENRY S. CARHART.

It is not necessary to enlarge upon the importance of a legal standard of electromotive force. It is quite as essential as a legal standard of resistance.

It will be remembered that the Chamber of Delegates of the International Congress of Electricians at Chicago in 1893 adopted a value for the electromotive force of the Clark cell and appointed a committee to prepare a specification for its construction. The committee consisted of Prof. Helmholtz of Berlin, Prof. Ayrton of London, and the writer. Unfortunately, before the committee reached an agreement, the eminent chairman died; the two remaining members being unable to agree, one form of cell was accordingly adopted by the British government, and another by the Congress of the United States. The latter represents the survival of the fittest, for reasons that were assigned in 1893.

Germany contented itself by legalizing the units of resistance and current.

The legal value of the electromotive force of the Clark cell is 1.434 international volts at 15° C. In the ten years which have intervened since the Chicago Congress, it has become quite certain that the actual electromotive force of the Clark cell at 15° C. is nearer 1.433 than 1.434. Indeed, the Helmholtz absolute electrodynamometer at the Reichsanstalt, gave in the hands of Dr. Kahle, 1.4322 volts. This value has not been used at all, but for the past six or seven years 1.4328 at 15° C. has been used at the Reichsanstalt. This value was not obtained by means of absolute measurements but by the silver voltameter, corrected by reference to the measured ratio between the electromotive forces of the Clark and cadmium cells.[1] But the electrochemical equivalent of silver is not known with any greater accuracy, to say the least, than the electromotive force of the Clark cell. Hence, the Reichsanstalt method is open to grave objections.

In 1899 an absolute determination of the electromotive force of the Clark cell was made by the writer and Dr. Guthe.[2] The result was 1.4333 at 15° C. We have never regarded this value as final, because certain changes in the dimensions of our absolute electrodynamometer did not permit us to repeat the measurements a sufficient number of times to get a satisfactory series.

Later Dr. Barnes of McGill University made a series of determinations of the mechanical equivalent of heat in terms of the international electrical units. His results will agree with those of Reynolds and Moorby, made by a purely mechanical method, if the electromotive force of the Clark cell is 1.43325 at 15° C.; and they will agree with Rowlands if the Clark is 1.43355.[3]

During the past year we have again taken up the matter with the purpose of measuring the electromotive force of the Weston cadmium cell and the electrochemical equivalent of silver. The Weston cell, with a saturated solution and excess of cadmium sulphate crystals, is chosen because of its low temperature coefficient and the close agreement between the different cells of a series. The temperature coefficient of this cell has been so carefully determined at the Reichsanstalt that it is not necessary to repeat that part of the work. For cadmium cells with saturated solutions and an excess of cadmium sulphate crystals, the formula for the electromotive force at any temperature between about 10° C. and 30° C., is

$$Et = E_{20} - 0.000038\ (t-20) - 0.00000065\ (t-20).^2$$

Further, the ratio, Clark 15°, cadmium 20°, has been determined at the Reichsanstalt in several series of comparisons with the greatest care and the most refined precautions. In one of these series the writer assisted. Giving due weights to the several series, the result is as follows:

$$\frac{\text{Clark at } 15^\circ}{\text{Cadmium at } 20^\circ} = 1.40670$$

An absolute determination of the electromotive force of the cadmium cell is therefore one also of the Clark cell, for the

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1. *Phys. Rev.*, Vol. XII, No. 3 1900.
2. *Phys. Rev.*, Vol. IX, No. 5, 1899.
3. *Phil. Trans.*, Series A, Vol. 199.

above ratio is known with much greater accuracy than we can measure the electromotive force of either in absolute measure.

Our absolute electrodynamometer has been rebuilt for permanency as follows: The stationary coil is wound in a single layer of 593 turns of No. 22 silk covered wire, on a plaster of Paris cylinder a little more than 47.3 cm. in diameter. The variation in diameter from one end to the other is only about one-tenth of a mm. The winding is about 41 cm. long, or the length is to the mean radius of the axis of the wire as $\sqrt{3}$ to 1.

The suspended coil, consisting of No. 22 wire rolled flat, is wound in 40 turns in a ground porcelain cylinder 10 cm. in diameter. This cylinder is suspended by a phosphor-bronze wire a meter long and approximately 0.7 mm. in diameter. The theory of the instrument and its construction were fully described by Patterson and Guthe in their paper on " A New Determination of the Electrochemical Equivalent of Silver."[1]

The preliminary measurements on the cadmium cell, which we hoped to make before this meeting, we have not been able to carry out. A series of cadmium cells, with amalgam containing 12.5 per cent. cadmium, have been made. No pains have been spared in the preparation of materials throughout. The cells agree well among themselves, the variations being smaller than the limits of accuracy we are attempting.

The very low temperature-coefficient of the cadmium cell is an advantage of the greatest importance, and the uniformity shown by different series of cells is so marked as to constitute another count in its favor as a standard. No definite specification has ever been drawn up for the construction of this cell. I have therefore the following recommendations to make:

First.—That the INSTITUTE appoint a committee of three to prepare a complete specification for the normal cadmium or Weston cell.

Secondly.—That the cadmium cell, as thus specified, shall be adopted by the INSTITUTE as the standard of electromotive force, and that steps be taken to secure its legal adoption by Congress, provided it be dedicated to the public by the inventor, one of the distinguished Past-Presidents of this INSTITUTE.

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[1] *Phys. Rev.*, Vol. VII, No. 39, 1898.

Discussion.

President Scott:—It is almost superfluous to express the appreciation which we have for work of this kind and the excellent results which Dr. Carhart has presented to us. His name is a guarantee for what is the principal thing in this paper, which is its accuracy and reliability. Is there discussion upon this?

Mr. Sharp:—I wish to second very warmly Professor Carhart's recommendations. This matter of the legal standard of e.m.f. is a very important one. The difference which exists now between the standard e.m.f. in use in Germany and our own amounts nearly to one-tenth of 1 per cent. In other words, their volt is one-tenth of 1 per cent. different from ours. Now, in most engineering work that is not a matter of very great importance, but in any work of precision it is a matter of great importance, and it is extremely desirable to get rid of this intolerable difference.

The simplest and best way to do it would be to abandon the Clark cell as our primary standard of e.m.f. The Clark cell is a rather troublesome thing to use in work of precision. With it it is not so easy to attain an accuracy of even one-tenth of 1 per cent., on account of the uncertainty as to what the exact e.m.f. of the Clark cell is after it has undergone temeprature changes. After abandoning our present standard we should, as Professor Carhart has suggested, go over to the cadmium cell, which is in every way better adapted for use as a primary standard of e.m.f. The cadmium cell is more easily prepared than the Clark cell and it is much more easy to use than the Clark cell.

The one necessary thing to this end is that sufficient representations be made to Mr. Weston to induce him to add to the great contributions which he has already made to the progress of electrical science, this one other contribution; namely, that he shall dedicate to the use of the public this cell. This dedication need not include the cell which is made and sold by the Weston Electrical Instrument Company, which is the undersaturated solution cell. The saturated-solution cell, which alone is adapted for use as a primary standard, is not, I believe, on the market in any form at the present day, and can be obtained practically only by making it one's self. If Mr. Weston were to consent to this, I believe we should signalize an event of considerable importance by going over, as the result of the deliberations of the forthcoming Congress, to the cadmium cell as a common and fixed basis for measurement.

Let me emphasize in this connection the importance of the standard cell to engineers in practical work. It will be conceded that no electrical laboratory, at least no college or technical school laboratory, is complete without an apparatus like the Wheatstone bridge. Nobody thinks of getting along without that. But you see a great many such laboratories that are utterly destitute of a potentiometer. Now, to my mind a potentiometer is an instrument of far greater engineering importance than the Wheatstone bridge, if we can compare things both of which are so necessary. We need in engineering to measure two things; namely, e.m.f. and current. For measuring both of those according to the best methods we need a potentiometer in connection with a standard cell. The impression is, I think, rather widespread that standard cells are delicate things which must be handled with a great deal of care in order to get good results with them and not to destroy them. This impression is erroneous. The standard cell will submit to a good deal of bad usage and will recover from it. Short-circuiting a properly constructed cell will destroy its usefulness as a standard for a while, but after a comparatively short period, a day or two perhaps, it is back again where it ought to be and is uninjured. It is an extremely reliable thing to use. The potentiometer can be made in such a simple form that it can be applied in any engineering practice with very great facility, so that it is quite feasible to make it an adjunct practically of every central station, an instrument by which every central station man can keep his pressure exactly where it ought to be, can check his voltmeters and know what their errors are. Moreover, these checks can be made in positions where the ordinary electromagnetic direct-reading voltmeter is utterly at fault; that is, in the vicinity of heavy feeders and bus-bars carrying large currents, etc.

I think it is important, then, that the INSTITUTE take some action such as has been suggested in regard to the matter of a standard cell, and that it should aid in every way in the very important work which Prof. Carhart has in hand, of determining the value of the e.m.f. of the Weston cell.

MR. CARL HERING:—I thoroughly agree with the recommendation of Professor Carhart concerning such a committee, but would like to add that it would be well for that committee also to recommend specific and distinctive names for the two different cadmium or Weston cells, so as to avoid the confusion which now exists. At present it seems that the saturated cell is called the cadmium cell, and the unsaturated one is called the " Weston cell." It seems to me that the first one, being the real standard, should bear Weston's name. I would therefore recommend that the saturated cell be called the Weston cell, partly because its defeated rival for first place is also called by the name of its inventor, namely, Clark; and that the unsaturated cell be given some different name. The voltages of the two are slightly different, that of the unsaturated cell being the voltage of the saturated cell at 4° Centigrade, at which temperature it is saturated.

I also think it is advisable to change the value which we have now adopted for the Clark cell, and make it conform more accurately to the theoretical definition of the volt. I am afraid there is a tendency to adopt as final, the present value of the Clark cell and to adhere to it, even though it may not agree with the absolute units. If we do not get a better agreement we will in time have to have such a thing as a mechanical equivalent of electrical energy; at present this factor is a simple multiple of 10, but unless the value of the Clark cell is determined more accurately it is likely that some such incommensurate number will have to be used for accurate calculations.

PRESIDENT SCOTT:—Professor Carhart at the end of his paper has made certain recommendations. The committee which he has suggested will probably be one appointed by the Board of Directors of the INSTITUTE. If it is your pleasure a motion asking the Board of Directors to give it their consideration, may be made now.

PROFESSOR GOLDSBOROUGH:—In this country we are on the point of bringing into complete being a standardization laboratory under the auspices of the government at Washington. This Bureau is very hopeful of being drawn closely in touch with the electrical engineering profession and does not wish in any sense to have it considered as a physical laboratory, which is separate and apart from the electrical profession. I would like to make a motion which will incorporate the ideas which Professor Carhart has voiced, and, in addition, one other; namely, that a committee, such as that specified by Professor Carhart, be appointed by the Directors of the INSTITUTE, to report at the general meeting of the INSTITUTE which will be held in St. Louis in September, 1904, and that 25 copies of Professor Carhart's paper, together with the discussion on the same, be sent to the secretary of each of the National electrical engineers' societies abroad, and also to the secretary of each of the several standardization laboratories in Europe.

MR. HERING:—In seconding this motion, I would like to offer as an amendment, that this report be made as soon as possible, in order to give time for expressions of opinion both in this country and abroad, before the next Congress meets. It seems to me to be a mistake to *discuss* matters of this kind at the Congress. The real object of a congress is to *settle* a discussion. The discussion should precede the meeting of the Congress. I therefore beg leave to suggest the amendment that the committee report as soon as possible, say, early in the fall.

PROFESSOR GOLDSBOROUGH:—I would be very glad to incorporate that in the original motion, Mr. President.

(The motion was then put and carried.)

PROFESSOR CARHART:—Just a word or two more, please. I may say that our experience with this form of electrodynamometer is sufficient assurance to us that the new one will give us results on which we can depend. We are simply making an instrument the parts of which we shall know with greater certainty.

Secondly, I am very certain that the Bureau of Standards is heartily in sympathy with this whole matter. It may not be known to members of the INSTITUTE that Assistant Professor Guthe of my Department has recently been retained, I am very sorry to say, by the Bureau of Standards, to do exactly this work there, and they are proposing to duplicate this instrument of ours as soon as they are able to (but of course we shall be far ahead of them, a good many months, perhaps a year of two), for the purpose of making similar measurements. I saw Professor Rosa, the physicist of the Department this week. So that I know they are entirely in sympathy with the whole movement; and, while I do not wish to dictate at all, merely to suggest, it would be very fitting if a member of the Bureau who is also a member of the INSTITUTE, were placed on this committee.

(On motion of Mr. Dunn, seconded by Mr. Hering, the report was adopted by a rising vote.)

PRESIDENT SCOTT:—The next paper is No. 8, " The Magnetic Units," by Doctor A. E. Kennelly.

Doctor Kennelly read the paper referred to, as follows:

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 2, 1903.

MAGNETIC UNITS AND OTHER SUBJECTS THAT MIGHT OCCUPY ATTENTION AT THE NEXT INTERNATIONAL ELECTRICAL CONGRESS.

BY A. E. KENNELLY.

The committee appointed by the British Association for the Advancement of Science for the selection and nomenclature of dynamical and electrical units, published its first report in 1873.

That report recommended the adoption of the centimetre, gramme and second as the respective fundamental units of length, mass and time, on which the dynamic and electromagnetic systems of units should be based. The centimetre was selected in place of the metre, so as to make the density of water equal to unity.

The C. G. S. system of units thus promulgated, has become the recognized international scientific unitary system. It has met with almost universal satisfaction.

In constructing the C. G. S. basic units of electricity and magnetism, it is now easy to perceive that a bad selection was made. The unit magnetic pole was chosen as one which repelled its prototype at unit distance with unit force. A better selection would have been the pole which emitted unit magnetic flux, with a similar definition for the unit electric point-charge. The assumed system of electromagnetic units, thus amended, is sometimes spoken of as the "rational" system, in contradistinction to the existing system, which is then described as the "irrational system." The rational system would be more simple to express and to remember, for the reason that the numerical constant 4π or 12.566, which now appears in many fundamental electromagnetic equations, would have been eliminated and introduced into spherical problems, where the constant naturally belongs. For example, the m.m.f. in a magnetic circuit would become equal to the current-turns linked therewith, instead of 4π times the current-turns. Consequently, many spherical electromagnetic problems that would naturally expect the 4π constant, now exclude it, and plane or rectangular problems, that would be simpler without it, now embrace it.

This criticism could scarcely have been foreseen at the time the C. G. S. electromagnetic system was constructed. It has taken years of acquaintance with the system to make the defect apparent.

If we could go back with our present knowledge, and create the C. G. S. electromagnetic system afresh, it would probably be better to adopt the "rational" system. To make the change now would require changing the magnitudes of the ohm, volt, ampere and other magnetic units by some power of 4π. The only exceptions would be the watt and the joule. They would escape.

It would be very troublesome to change all our electromagnetic measures. The trouble would be felt by every electrical industry. The change could only be made effective by international agreement. The only compensation for the trouble and expense would be a certain amount of scientific simplification in the theory of electromagnetism, and a certain benefit to scientific computers. The electrical industries would not receive any practical benefit, and any benefit they could receive would be that small indirect amount derivable from the simplification in theory already mentioned.

It seems too late, therefore, to attempt reconstructing electromagnetic units upon the C. G. S. system on a more rational basis. The majority would be inconvenienced for the benefit of the minority. It seems better that the student minority should make a little more effort to work with the existing "irrational" uints, than to upset the existing order of electromagnetic measure in the hands of the many. In fact it is probably inadvisable for scientists to adopt the "rational" system in their writings, since the labor of reading electrotechnical papers is often greatly enhanced by the uncertainty as to which of the two systems is being employed.

The case is reversed as regards the rational use of the metric system of weights and measures. In this country, and in Great Britain, the system of customary weights and measures is a burdensome incoherent medley with absurd inconsistencies and ambiguities. The metric system is far simpler and better, besides being in otherwise international use. The change from the customary to the metric system would entail much trouble and some expense, but it would effect a great reduction of aggregate national labor in learning, employing, exchanging and computing. The change would be nationally economical, so far as can be judged from the internal evidence presented, as well as from the evidence of the various countries that have already made a similar change.

Several ingenious expedients have been proposed for effecting partial "rationalization" of the C. G. S. electric and magnetic units, without changing the values of the concrete practical units. All thus far proposed introduce a new factor into fundamental or defining equations in order to get rid of the 4π constant in other equations, so that the 4π difficulty is thereby not eradicated but merely transported. It is very doubtful whether such half-hearted expedients can succeed. It seems better to let the existing system alone.

In adapting the C. G. S. system of magnetic units to practical requirements, the inconvenient magnitudes of many C. G. S. units became apparent. The C. G. S. unit of e.m.f. was ridiculously small, since an ordinary Daniell cell showed 110 millions of them. A similar condition was found for the C. G. S. unit of resistance; since a Siemens unit, in extended use at that time, containing about a trillion C. G. S. units. In order, therefore, to aid practicians, the working unit of e.m.f. was selected as 10^8 C. G. S. units of e.m.f. under the name of the volt; while the working unit of resistance was selected as 10^9 C. G. S. units of resistance, under the title of the "ohm." These practical magnitudes having once been adopted, a practical system of units inevitably came into existence, one volt through one ohm producing one ampere; one ampere carried for one second delivering one coulomb, and so on. The practical units differed from their parents, the corresponding C. G. S. units, by differing multiples or powers of 10. In one instance, the ratio between a C. G. S. unit and its practical representative is 10, in another it is 10^9, in another 10^7, and so on. Moreover, the practical system of the ohm, volt, ampere, coulomb, joule, watt and henry, is such as would have been arrived at directly, if the unit of length had been an earth-quadrant, or 10^9 centimetres, instead of one centimetre, and the unit of mass 10^{-11} gramme, instead of the gramme, the unit of time being the second in both systems.

Thus there has been created the fundamental centimetre-gramme-second system in which the theory of electromagnetics is learned, and to which all science is referred. Side by side with the C. G. S. system is the practical, or quadrant-eleventh et gramme-second system, or Q. E. S. system, in which most of the units have been christened for industrial use. The C. G. S. system is thus the language of the esoteric; while the Q. E. S. system is the electrical vernacular.

The divorce of the practical from the scientific system was a grave mistake, although it was probably hard to foresee. After years of experience it is now easy to see that the correct original course would have been to christen the C. G. S. magnetic units, without regard to their particular magnitudes, and, at the same time, to adopt a suitable series of prefixes for decimal multiples and submultiples, in extension of the existing micro-milli-kilo-mega system. If, for example, the C. G. S. magnetic unit of current-strength (10 amperes), had been originally christened the ampere, our present ampere would have been known as the deci-ampere, and in a few days we should have become as familiar with such a deci-ampere as we are with the existing ampere. This is shown by the case of the *microfarad*, which is as simple and convenient a term as if this standard capacity had been originally called the farad. We should then have retained the C. G. S. system for both the esoteric and the vernacular, but would have adopted for practical work certain multiples with their apporpriate prefixes.

It is probably now too late to retrace our steps. We cannot annul the Q. E. S. system and exclusively adopt the C. G. S. system for practical work. Nor is it worth while upheaving decimal relationships. Thus, it has been suggested that the existing dekavolt might be changed in name to the volt, by increasing the volt to ten times its present magnitude, in order to make the new ampere agree with the C. G. S. unit of current. This would entail a slight advantage over the existing practical system. It would, however, effect a confusing hiatus in technical literature and would still leave a practical system divorced from the C. G. S. system with numerical ratios of 10^{-9} and 10^{9}. The Q. E. S. system is in satisfactory industrial use all over the world, so far as it goes; viz., through the eight units: volt, ampere, ohm, farad coulomb, henry, joule, and watt. But we can with advantage stop further unnecessary divergence, by refraining from christening any more units in the Q. E. S. system, and by bestowing all future names on the C. G. S. system. A start in this direction has already been made. The international electrical Congress at Paris in 1900 christened the C. G. S. magnetic units of flux and flux-density, under the names of maxwell and gauss respectively. These terms have already come into fairly extended use in America and into somewhat more limited use in Europe.

It is very desirable that the next international electrical congress should complete the units of the magnetic circuit by bestowing names upon the C. G. S. units of m.m.f. and of reluctance. The AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS has for several years provisionally recommended the names "gilbert" and "oersted" for these two units. They are already in some use in America. If they should be adopted, we would have the relations:

$$\frac{\text{gilberts}}{\text{oersteds}} = \text{maxwells}$$

$$\frac{\text{maxwells}}{\text{sq. cms.}} = \text{gausses}$$

The ampere-turn is a very convenient unit of m.m.f. close to the C. G. S. unit in order of magnitude; but a name for the C. G. S. unit is very desirable.

By rights, every C. G. S. electromagnetic unit should have a name. There is not even a recognized weed, or germ, that does not have a name. Practically all the fifteen hundred millions of people inhabiting the world have names. It would seem that a fundamental C. G. S. electric or magnetic unit is of as much importance as a weed or a bacillus. Moreover, it is fortunately unnecessary to learn the names for units, or commit them to memory, if the units are rarely used. It would be sufficient to have authorized names accessible and definite, ready for use when required.

Moreover, our minds are so constituted that until we possess a name for a thing, the thing remains more or less symbolical, and is not fully realized as concrete. Thereby the C. G. S. system of electromagnetic units, which is necessary and fundamental becomes hampered and retarded. It is desirable for scientific purposes, for educational purposes, and in the interests of progress, that these international C. G. S. units should have recognized names.

For example, the fundamental rule for the electromotive force of a direct-current bipolar dynamo is

$$e = \phi\, n\, w. \quad \text{C. G. S. magnetic units of e.m.f.}$$

where ϕ is the useful flux from pole to armature in maxwells, n the speed of rotation in revolutions per second and w the number of wires on the surface of the armature. If we divide e in this equation by 10^8, we get the result in volts; but the *C. G. S. magnetic unit of electromotive force* is worthy of a name, if only to avoid the objectionable periphrasis.

The expedient suggests itself of attaching the prefix *ab* or *abs* to a practical or Q. E. S. unit, in order to express the absolute or corresponding C. G. S. magnetic unit. The advantages of the plan are that it is almost self-explanatory, and requires no effort of memory to acquire; also that it is self-suggesting in all the important European languages. According to this plan the

C. G. S. magnetic unit of e.m.f. would be the abvolt
" " " " resistance " " absohm
" " " " current " " absampere
" " " " quantity " " abcoulomb
" " " " capacity " " abfarad
" " " " inductance " " abhenry or centimetre
" " " " energy " " abjoule or erg
" " " " power " " abwatt

We would also have the following ratios:

1 abvolt = 0.01 microvolt = 10^{-8} volt
1 absohm = 1 bicrohm = 10^{-9} ohm
1 absampere = 1 dekampere = 10 amperes
1 abcoulomb = 1 dekacoulomb = 10 coulombs
1 abfarad = 1 begafarad = 10^{9} farads
1 abhenry = 1 bicrohenry = 10^{-9} henry = 1 cm.
1 abjoule = 0.1 microjoule = 10^{-7} joule = 1 erg
1 abwatt = 0.1 microwatt = 10^{-7} watt

On such a basis the preceding equation would be written

$$e = \phi\, n\, w \text{ abvolts,}$$

with great advantage in clearness and comprehensibility.

In a comprehensive system of electromagnetic terminology, the electric C. G. S. units should also be christened. They are sometimes referred to in electrical papers, but always in an apologetic, symbolical fashion, owing to the absence of names to cover their nakedness. They might be denoted by the prefix *abstat*. Thus, the

C. G. S.	electric	unit	of e.m.f.	would	be the	abstatvolt
"	"	"	" resistance	"	"	abstatohm
"	"	"	" current	"	"	abstatampere
"	"	"	" quantity	"	"	abstatcoulomb
"	"	"	" capacity	"	"	abstatfarad
"	"	"	" inductance	"	"	abstathenry

The abstatjoule and abstatwatt are the same as the abjoule and abwatt respectively. These units would almost also be self-explanatory in any European language and would call for no appreciable effort of memory.

We should then have the following ratios ($v = 3 \times 10^{10}$ approximately):

1 abstatvolt	$= v$ abvolts	$= 300$ volts
1 abstatohm	$= v^2$ absohms	$= 9 \times 10^{11}$ ohms
1 abstatampere	$= v^{-1}$ absampere	$= 3.3 \times 10^{-10}$ ampere
1 abstatcoulomb	$= v^{-1}$ abcoulomb	$= 3.3 \times 10^{-10}$ coulomb
1 abstatfarad	$= v^{-2}$ abfarad	$= 1.1 \times 10^{12}$ farad
1 abstathenry	$= v^2$ abhenrys	$= 9 \times 10^{11}$ henrys*

It is desirable that such system of christening the C. G. S. magnetic and static units, without burdening the memory, should be adopted by an international electrical congress.

It seems also desirable that an international electrical congress should sanction the use of the Hefner Alteneck Reichsanstalt standard amyl-acetate lamp as a secondary standard of light or luminous intensity. The lamp is in extended use for determining the intensity of incandescent lamps, and as such should receive recognition.

It is also desirable that steps should be taken by an international electrical congress to establish a uniform international basis for the standardization of electrodynamic machinery. The AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS has already formulated, through the work of a committee, a series of standardization rules, relating to nearly all classes of dynamo-electric machinery. A similar series of rules differing from the last named in various details has been promulgated in Germany by the Verband der Deutcher Electroteckniker. Still other rules are extant locally in other countries. It is perhaps possible to carry the principal of international standardization too far into detail, since many details depend in each country upon local,

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*The abstat henrys regarded as a length according to the conventional system of dimensions contains 9×10^{11} earth quadrants, a distance that light would take nearly one thousand years to cross.

commercial and industrial conditions; but, on the other hand, there are many underlying physical and electrotechnical conventions that might receive international consent among electrical engineers. For example, a dynamo machine ought to have the same rating, based on temperature-elevation under load, all over the world, and the rules by which the rating of a dynamo is experimentally determinable might well be adopted by an international electrical congress, together with many similar matters, under this general title of standardization. Such a concensus of opinion would probably take time to evolve and an international electrical congress might appoint a standing committee to confer upon the question of standardization with instructions to report at a future time. Much scientific and engineering benefit might be hoped for from the efforts of such a standing committee on international standardization.

DISCUSSION.

MR. HERING:—I did not understand whether the prefix " ab " for the C. G. S. units was to apply to the electromagnetic units or to the electrostatic, or to both. If it applied to both there would be confusion. I presume it is intended to be applied only to the electromagnetic units.

Doctor Kennelly said that the last Congress at Paris in 1900 *created* some units. That is not quite right. It did not *create* them, it simply *named* some existing absolute units.

PROFESSOR GOLDSBOROUGH:—Before we pass on to the next paper, may I be permitted to say a word or two in reference to Doctor Kennelly's paper? For a number of years past I have found it very convenient indeed to make up a few names for the magnetic units which thus far have not been christened, and use them commonly in discussing matters pertaining to electromagnetism with our students. I have found that as soon as we can give to the student a definite name for a specific thing, he gets a concrete idea of what it is very much more readily.

We are nearing the time when we shall undoubtedly use the metric system in all engineering work. The Mechanical Engineers are taking the matter up for serious consideration, and consideration has been given the matter by the INSTITUTE. It is only a question of time when the English measures will pass out and the metric system will come in. Why should we not, then, prepare for this by having the magnetic units properly named so that ultimately when we begin to speak, say, of magnetic reluctance per centimeter, we shall have specific unit of measure of this quantity. To my mind it is highly important the new generation of engineers that is coming should get correct conceptions of what all the units stand for.

I should like, Mr. President, to offer another motion, to the effect that copies of Doctor Kennelly's paper when printed be sent, with copies of Doctor Carhart's paper, to the secretaries of the various institutions mentioned, for distribution and for the purpose of calling attention to matters that have been under discussion here this morning.

PROFESSOR J. P. JACKSON:—Mr. President, in seconding that motion, I wish to suggest that Doctor Kennelly was exceedingly delicate with reference to existing standards, and rightly so; and on the other hand, he wished to get as nearly as possible to our fundamental system. I feel that in his paper he can afford to use a good deal of positiveness in reference to a method of arranging new units whereby our literature, which is growing rapidly and assuming permanent shape, will not have any constants whatsoever, at least so far as standard formulas are concerned. I second Professor Goldsborough's motion.

(Carried.)

MR. HERING:—Doctor Kennelly gave the impression that the Hefner unit of light was the one generally used in this country. Some time ago I was anxious to know whether this was or was not the case, and therefore made inquiries which showed that the prominent gas lighting and electrical lamp companies use the British candle, which is a larger unit than the Hefner. Measurements are often made in terms of the Hefner unit, and are then reduced to the uncertain British candle.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 2, 1903.

THE CATHODE RAY ALTERNATING CURRENT WAVE INDICATOR.

BY HARRIS J. RYAN.

During the past three years I have had considerable experience in the use of the Braun type of cathode ray tube to determine the character of rapidly changing electric currents. In this experience I developed the following method for using this form of tube as an alternating current wave indicator. By means of the method this instrument fills much the same sort of a want in the detail study of many alternating current phenomena as does the indicator in the study of the cyclic performance of steam in the steam engine.

I have found the method so convenient and satisfactory in a large class of work compared with other and more usual methods that I am confident that many members of the INSTITUTE will find its employment often convenient and most useful in their own work.

DESCRIPTION OF THE METHOD.

The usual form of cathode-ray tube employed for indicating alternating currents is shown in Fig. 1. The cathode and annode are connected to the negative and positive conductors respectively of a motor-driven Wimshurst electrostatic machine. A current of about .0005 ampere is set up in so doing and the cathode rays are driven forward through the tube, striking the glass diaphragm which is opaque to them. All of the rays are stopped at this diaphragm except those which pass through a small aperture at its center. This pencil of rays continues until it strikes the screen where it causes a brilliant spot of fluorescent light. The screen is of mica spread with white powder that powerfully fluoresces when struck by the cathode ray.

Comparatively weak magnetic fields will cause large deflections to the ray. Thus if a continuous current be passed through the coils, c′ c′, mounted just beyond the diaphragm as shown in Fig. 1, of sufficient strength in regard to the number of turns in the coils so as to produce a m.m.f. of about 50 ampere-turns, the ray will be deflected well to one side of the center of the tube, causing a corresponding displacement of the spot of light on the screen to the point marked +. Such deflection is due to the magnetic field set up across the cathode ray by the current in the coils. When the current ceases the spot of light produced by the ray returns to its normal position at 0. If the current is set up in an opposite direction, the spot of light will shift on the screen to the point marked –. When an alternating current having the same maximum value is substituted for the continuous current, the spot of light will vibrate between the + and – positions, and owing to the persistence of vision will appear as a band of light.

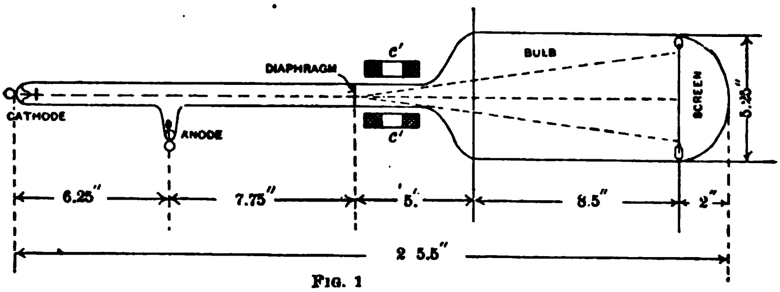

FIG. 1

By looking at the screen as seen reflected from a revolving mirror, the spot of light actuated by an alternating current will trace a wave that will have the same form as the wave of current which is passed through the coils due to the fact that the cathode ray has no appreciable inertia. Some investigators have revolved the mirror synchronously and thus obtained a stationary wave which is most satisfactory to look at and which may be readily photographed. The synchronous driving and satisfactory adjustment of the revolving mirror involve expensive apparatus that is cumbersome and tedious in manipulation, to avoid the use of this apparatus I have devised the following method:

Reference is here made to Figs. 2 and 3. Two sets of coils are applied just beyond the diaphragm and mounted with their axes at right angles and in the same plane as shown in Fig. 2. The coils having the axis *ab* set up a horizontal field and which when established with alternating currents will produce the vertical motion of the spot of light producing a luminous band on the screen shown at *ab* in Fig. 3. Similarly, the coils having the axis *cd* produce the horizontal motion of the spot and the band *cd*. When the alternating currents are set up simultaneously through both sets of coil, the spot of light will be subject to both motions tracing the card shown in the figure.

In order that definite results may be obtained, only one of the wave forms of the two currents may be unknown; the other must be of known form. The most suitable known form is that of a true sine wave. To secure a true sine wave of current with ample accuracy for all practical purposes, I have employed the following arrangement of inductance and capacity. Referring to Fig. 4, *AC* are leads from an alternating source of unknown pressure wave-form supplying the current to an apparatus at *M* that is to be observed. The circuit through *M* leads through one set of coils mounted at c_1 c_1, so as to give a motion of the cathode ray that is proportional to the instantaneous values of the current through *M*. The current that produces the standard sine wave motion of the cathode ray passes through the coils c_2 c_2 with their axes at right angles and in the same plane of the axis of the coils c_1 c_1. This current is obtained from the source having an unknown pressure wave form at a' c'. It passes from c' through the single path L' and the paths C and L'' in multiple, and finally to the source at a'. The coils c_2 c_2 are connected in the branch L'' L' and L'' are inductive reactances made by mounting coils on straight laminated iron cores. The ohmic resistances are made as low as is ordinarily convenient and possible compared with the corresponding values of the reactances. C is an ordinary paper

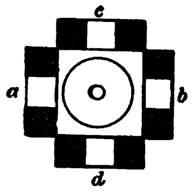

FIG. 2

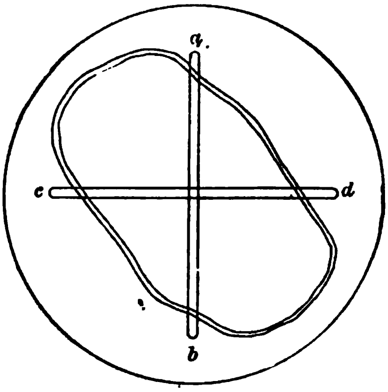

FIG. 3

condenser. The reactances of C and L'' are adjusted so as to be approximately equal and, therefore, so that resonance is established to some extent due to the exciting current that is set up through L'. All who have made a study of the characteristic properties or behaviors of the harmonic elements or component irregularities in relation to inductance and capacity will note at a glance the powerful action that this circuit will exert in expurgating the current that passes the branch L'' A c_2 c_2 of all irregularities causing it to have a simple sine wave form.

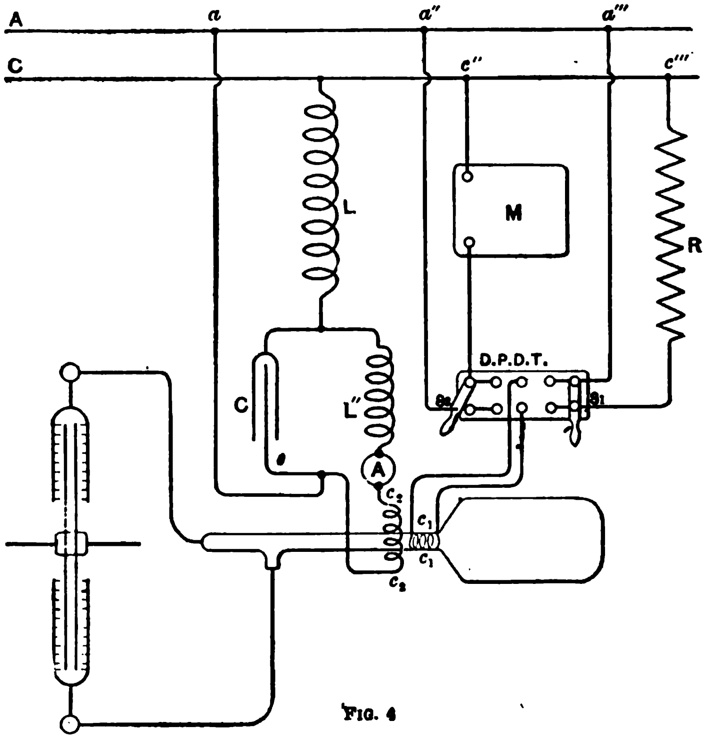

FIG. 4

I have usually adjusted this circuit so that a current of .2 ampere passed L', and 1 ampere circulated through the resonant circuit C L'' A c_2 c_2. Thus arranged the third harmonic will be reduced to *one-third* compared with the *fundamental* in passing L'; a further reduction of *one-third* of the third harmonic occurs through L'' which acts as a throttle for all harmonics while the condenser passes the third harmonics with a facility measured at *three times as easy* as for the fundamental. A further reduction factor of 5 to 1 acting alike against the third as well as all higher harmonics is applied by the current multiplying process due to resonance. All current circulated through $C\ L''\ A\ c_2\,c_2$ due to resonance must have the simple sine form so long as the saturation m.m.f.'s utilized by the iron cores are small compared with those used by the air cores in the magnetic circuit of L''. Thus it is seen that there are approximately the following factors which combine to cut out the third harmonic.

$$3 \times 3 \times 3 \times 5 = 135$$

which means that in the above circuit the value of the third harmonic compared with the fundamental circulating through $c_2\,c_2$ has been reduced to *one hundred and thirty-fifth* of the original value existing in the e.m.f. wave impressed by the source upon this circuit at $a'\ c'$. Since even in very bad cases of wave distortion in e.m.f. generation the third harmonic will not exceed one-third of the magnitude, it follows that the ratio of the fundamental and third harmonic values of the current through $c_2\,c_2$ is about *four hundred.* Since the higher harmonics are eliminated to a greater extent than the third it follows that the deviation of the current wave through the coils, $c_2\,c_2$, that are to produce the standard known motion of the ray, from the cyclic variation of a true sine wave is less than *one-quarter per cent.*, an accuracy that is ample for the purposes involved.

By means of the analytical methods published by Steinmetz, the exact degree of expurgation of irregularities in the wave of the original source is easily computed where " open " magnetic circuits employing straight cores operated at low flux densities are used in making up the inductances L' and L''.

The degree to which the above expurgation of irregularities will occur in actual operation has been examined carefully in a number of ways and found to be about as described above.

When the unknown current through M and the coils at $c_1\,c_1$ and the sine wave current through the coils at $c_2\,c_2$ are established at the same time, the spot of light on the screen in the cathode ray tube is given a motion that is the resultant of two motions at right angles to each other and proportional to the instantaneous values of their corresponding currents. Owing to the persistence of vision, this results in the production of a closed card upon the screen traced by the spot of light. A record of this card may be made in various ways; I have generally used one of the two following methods:

1. The card may be easily photographed in the ordinary camera using five seconds' exposure.

2. It may be traced on a smoked glass mounted in front of the tube by keeping the eye at a fixed point of view.

I have generally preferred to record the cards by photographing them.

Ordinarily the detail of the pressure wave with respect to the current wave that it established is also desired. By means of switches $S_1 S_2$ and *D P D T* in Fig. 4, the coils at $c_1 c_1$ can be disconnected from the circuit $a'' M c''$ and connected in the circuit which draws current through a non-inductive resistance $a''' R c'''$. This produces a card due to the pressure wave-form impressed upon the machine or apparatus at M. Obviously, when the currents through M and R differ widely in magnitude, an extra set of coils may be mounted concentric with the coils $c_1 c_1$ through which to receive the current controlled by the non-inductive resistance R. Both cards may be photographed on the same plate when a true record is obtained of instantaneous values and phase relations of the unknown e.m.f. and current applied at M. To enable the values to be plotted in rectangular coördinates, the axis of the standard or sine wave should also be recorded. This is easily done by removing the current from the coils $c_1 c_1$ and recording the line of light produced by the sine motion that remains due to the standard current in the coils $c_2 c_2$.

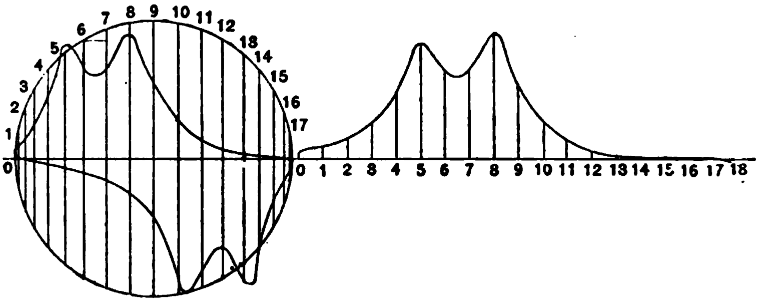

FIG. 5. E.M.F. WAVE OF OLD T-TOOTHED ARMATURE ALTERNATOR.

If a polyphase source is employed it is best to apply the sine wave current through the coils, $c_2 c_2$, from a pressure phase changing device. This is easily and obviously arranged by means of a set of autos having a number of pressure taps or by means of a movable coil mounted in a revolving field such as is provided by every induction motor that has a wound secondary. Thus the phase position of the sine wave can be adjusted so as to cause the more intricate portions of the unknown wave form to occur at the time when the sine wave motion is most rapid, *i. e.*, when the sine wave current is passing through zero. In this manner the resulting cards can be so adjusted as to bring out the desired detail to the fullest and clearest extent.

In a simple and obvious manner he values of the unknown wave may be taken from its card and plotted with time in rectangular coördinates. One way of doing this is illustrated in Fig. 5. A circle is drawn using the sine wave as a diameter. Upon this circle a number of equidistant points are located corresponding to the number of points to be used in plotting the wave iu rectangular coördinates. Ordinates to the sine wave diameter of this circle will intercept the card at uniform time intervals. The lengths of the ordinates from the card to the diameter are proportional to corresponding instantaneous values of the wave and may be transferred without change to the rectangular diagram to form the actual wave as shown in Fig. 5.

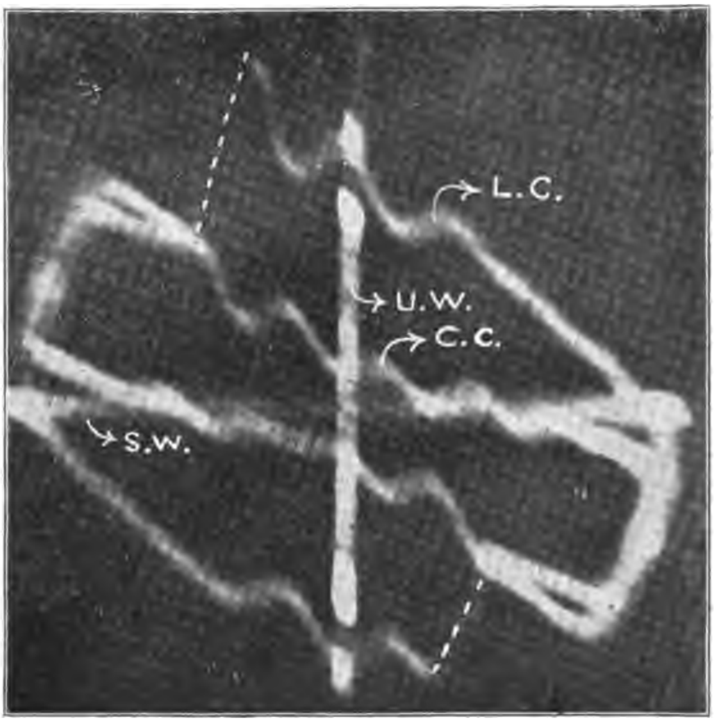

Fig. 6.

The scale that applies to the instantaneous values is determined by comparing the effective value of the observed wave with the reading of an alternating current ammeter placed in series with the sine wave coils, $z_2\ c_2$. This ammeter is read at the time that the card formed by the unknown wave is recorded. The ratio between the deflections of the ray produced by the coils $c_1\ c_1$ and $c_2\ c_2$ is easily obtained once for all by means of observations taken with continuous currents and instruments.

The half tone in Fig. 6 was made from a photograph of a set of cards and their axes as they were formed on the screen of the cathode ray tube. In making these cards the method was being employed in a study of the conductivity of the atmosphere about a line conductor subjected to high pressure. The card *L C* was formed by the line-charging current and the card *C C* by the charging current supplied to an air condenser for the purpose of determining the e.m.f. wave impressed upon the line. The coils corresponding to $c_1\ c_1$ in Fig. 4 in this instance contained a total of 46000 turns which would enable cards to be formed with currents of from .0006 to .006 ampere, *i.e.*, from .6 to 6 milliamperes. The effective e.m.f. employed was 40,000 volts at 120 cycles.

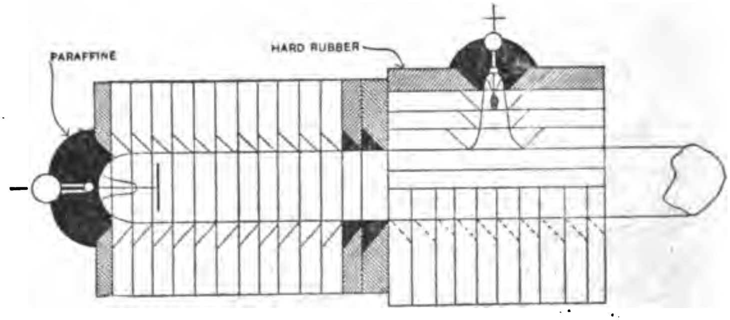

FIG. 7

In order to use this cathode ray instrument on high pressure circuits some natural precautions must be taken. The tube coils, Wimshurst machine and camera must be completely enclosed in a wire cage set upon high pressure insulators and connected to one terminal of the high pressure source. The branch $L''\ A\ c_2\ c_2$ delivering the standard sine wave from the low pressure source must be protected by inserting an insulating transformer so as to separate with an ample dielectric the coils $c_2\ c_2$ and the remainder of the low pressure circuit $L''\ A\ a_1'$. Such an insulating transformer is easily provided by mounting primary and secondary annular coils having a transformative ratio of 1:1 upon a straight open-circuit core and separated therefrom by a suitable space to be occupied by the dielectric and then by immersing the whole transformer in ordinary kerosene. Obviously all metallic circuits within the high pressure cage should be grounded to it. In this manner I have found that many of the interesting atmospheric conduction phenomena that occur in high pressure work may be studied experimentally in a satisfactory manner.

I think that this apparatus will in the future be found of use in observing the behavior of hunting currents in synchronous machinery, commutation in continuous current machinery, the characteristic manner of current interruption produced by fuse cut-outs, and circuit breakers and electric surges on long lines.

As was shown above, it is easily applied where cyclic phenomena are to be observed. It can, however, frequently be used effectively for observing values that occur only as sudden impulses, by having the current constituting the sudden impulse through one circuit and a uniformly increasing current through another circuit occur simultaneously and arranged so as to act magnetically upon the cathode ray. A momentary trace showing the nature of the impulse is thus drawn across the fluorescent screen.

When I determined to examine into the fitness of the Braun type of cathode ray tube for engineering research work I found that the tubes on the market were altogether too small to be of practical use. In the summer of 1900 Mr. Miller-Uhri of Braunschweig, Germany, undertook to make for us two tubes in which the screens would be as near to 6 inches in diameter as he could make them. The glass work is difficult and only after a number of trials did he succeed in making two in which screens were 5 inches in diameter. These landed in my laboratory in safety. A drawing to scale of one of these tubes is given in Fig. 1.

At the outset I was greatly disappointed in the behavior of this large size of tube compared with that noted in the small tubes. The cathode ray produced by the discharge from the influence machine was intermittent and almost wholly unsatisfactory. During the next two years I spent such available time as I could spare in a study of the causes of this intermittent character of the ray. The trouble was finally traced to conductivity of the atmosphere that occurs at the rather high pressure that must be applied between the cathode and annode of the tube. The pressure required will spark a distance of $\frac{3}{8}$ inch between 3 inch balls. As soon as the real cause of the trouble was understood the remedy was easily found and applied.

To cause the formation of a continuous steady ray, therefore, it is necessary to jacket the tube at the cathode and annode portion with an ample solid dielectric. Oil for this purpose is a complete failure because it is too mobile. The best manner as yet that I have found for applying the jacket, so as to keep the air away from the immediate exterior of the electrodes, is shown in Fig. 7. The jacket is built up from quarter-inch hard rubber discs and half discs cemented to the walls of the tube with paraffin in the manner illustrated.

Such a jacket completely overcomes the unsteadiness of the ray, enabling one to operate the tube from an ordinary Wimshurst machine by connecting its cathode and annode direct to the terminals. All metal parts and connections from the Wimshurst to the tube should nowhere have a radius of less than ⅛ inch, *i.e.*, the conductor should be at least ¼ inch in diameter.

I have found that a Wimshurst using six pairs of 17-inch micanite plates, driven at 200 r.p.m., would furnish about all the current that may be passed through the tube without puncturing. This gives a most brilliant spot of fluorescent light upon the screen. While attempting to drive more current through one of the tubes it was punctured when operating the Wimshurst at a speed of about 250 r.p.m. This tube will operate satisfactorily with the discharge from a Wimshurst having a single set of 18 inch plates. The amount of light at the spot seems to be proportional to the current-discharge through the tube, and therefore, to the number and size of the plates used in the construction of the Wimshurst.

Mr. Muller-Uhri is now prepared to supply these extra large tubes to the trade at an export price of about $20 at Braunschweig, Germany. The rubber jackets described above must be mounted after the tubes have been received from the makers. Doubtless in the near future some method will be found that will enable the maker to mount upon the tubes a proper and sufficient jacket before sending them out.

I wish to acknowledge the efficient and extensive assistance rendered by Professor J. O. Phelon in the early work done upon these large tubes, whereby I was ultimately able to trace the real cause of the intermittent character of the cathode ray.

DISCUSSION.

MR. DUNN:—I wish to express my appreciation of the wave-form tracer that Professor Ryan has just described, although I know that some of my friends here will say, " What has a direct-current man to do with wave-forms? " While it is a little off the line of the discussion perhaps it would be interesting to see why this form of wave-tracer is so valuable in direct current.

The ordinary frequencies of alternating currents are, say, from 25 to 60 cycles per second; the frequencies of lightning, hundreds of thousands per second. The direct-current man's frequencies are in the region between these and vary from about 800 to 8,000 per second. The latter frequencies occur in the complicated phenomena of commutation.

Many of these phenomena have yielded to experimental and other analyses but others have seemed beyond this with the methods available, but a curve-tracer such as Professor Ryan brings out will, I believe, be of the greatest assistance in the study of the complicated, irregular, high-frequency waves with which a direct-current armature is teeming. The inductive interferences in direct-current armatures have been greatly reduced by the study of these waves in the last few years; it is to be hoped that they may be still further reduced if we have a wave-form indicator like Professor Ryan's capable of dealing with the frequencies involved.

MR. THOMAS:—I would like to ask Professor Ryan how he best takes the records of these wave-forms, how much light he gets for photographic work. how long it takes, and also whether it is possible to get a changing phenomenon; that is to say, a discharging condenser where there are no two waves alike.

PROFESSOR RYAN:—It is not possible, Mr. Thomas, to photograph single tracings? The light that is given off by either the luminosity of the cathode or the fluorescent screen is not strong enough for that after being transmitted through the mica screen and the glass of the tube. However, for periodic work it is easy to photograph, as photographic apparatus is usually made up with regard to sensitiveness of the plates and all that, with an exposure of from two to five seconds, depending on the strength of the current that we are running through the cathode ray tube, for the invokement of the ray; and for all ordinary inspectional work a very convenient method is simply to have a fixed point of view for the eye and a lightly smoked glass in front, and you can trace the card with any convenient tracing point.

PROFESSOR A. F. GANZ:—I should like to ask Professor Ryan whether all the records come out in the form of such broad bands as are shown in Fig. 6, page 1423, and if they do I should like to ask how he passes from these broad bands to the well-defined lines shown in Fig. 5.

PROFESSOR RYAN:—That in Fig. 5 was a tracing on smoked glass taken by looking at the center of the line. It should be remembered that Fig. 6. in order to reproduce well, had to be taken at an exposure of 10 seconds, and that was on a 130 cycle circuit, and the cathode-ray tracer went around there 1300 times. You can see that although the line is somewhat broadened it repeated itself fairly well; and it is somewhat remarkable that retracing 1300 times did not give a broader record than we have there. In running during a two or three seconds exposure, instead of ten, the line would be narrower than that under ordinary conditions. The lantern-slide here exhibited was made at a time when we didn't have complete facilities, had only a small Holz machine for exciting the ray, and that was very weak, and the exposure there had to be made for five minutes instead of two or three seconds.

MR. WILLIAM J. HAMMER:—I would like to ask Professor Ryan whether he has ever used the Lenard tube with an aluminum window so as to bring the cathode ray outside, which will perhaps enable him to get rid of any possible error due to the mica and the glass, and enable him to make a record directly on photographic paper by means of a moving picture-film. Single images could be readily obtained by regulating the speed of the film. I have been doing some little work with a Lenard tube recently, and it occurred to me that perhaps that could possibly be used in this apparatus, and I would like to know whether Professor Ryan has tried it or whether he considers that it would be practicable.

PROFESSOR RYAN:—I have not done so. That is a very interesting suggestion indeed. I do not know how one would succeed.

DR. SHARP:—I think the facts concerning the Lenard arrangement are these, that the cathode rays which are obtained through the window are very quickly absorbed by the atmosphere; that they do not go any considerable distance outside.

MR. HAMMER:—Mr. Tesla told me recently of some experiments he had made in which he used a very powerful apparatus, and he spoke of drawing the rays outside of the Lenard tube, and in a 30 seconds exposure losing all the nails on one hand, and he spoke of being able to carry the stream a considerable distance, even stating that with a specially designed tube for very high voltages he could kill a man a mile off. So it would depend largely on the character of the apparatus which produced the cathode stream; I have myself succeeded in bringing it out a farther distance than you have referred to.

MR. FISHER:—I am very much interested in this apparatus and would like to ask Professor Ryan whether this apparatus can be produced complete so that the manufacturer can take it and use it immediately. The manufacturer does not want to adjust his self-induction and capacity to get an exact sine wave.

PROFESSOR RYAN:—In reply to that, the apparatus as shown in the diagram on page 4 for the securance of a sine wave known motion of the ray is that which you have in any testing laboratory and is so easily set up that I scarcely think any one would care very much to buy an especially produced outfit, because that same apparatus at other times might be used for other purposes. It is easily put together and the sine wave invoked. It has always occurred to me in that way. I use the same apparatus on another day for other things.

PROFESSOR LANGSDORF:—It is interesting to note in Fig. 4, on page 1420, that the means for obtaining the sine wave consists of two choke-coils in series and a condenser connected across from the middle point of these two to the other side of the line. If the two choke-coils have equal inductances, and if the capacity reactance of the condenser is numerically equal to that inductance, we have the constant potential constant current transformer system.

About two years ago, at Professor Ryan's suggestion, I made some calculations to determine whether there was any special relation between the values of L', L'' and C, which would produce a maximum damping out of the harmonics. This was done by the use of the complex imaginary quantity; it developed that there was no special condition of maximum damping, but that by changing the relations between these quantities a definite amount of damping could be obtained.

PROFESSOR GOLDSBOROUGH:—I feel very strongly that the INSTITUTE owes Professor Ryan a very hearty vote of thanks for the paper which he has given us to-day. Professor Ryan has given us an instrument which is, I believe, far superior to any other curve-tracing instrument that has thus far been brought forward. It is free from a great many of the drawbacks of other instruments and it has few parts that will get out of order. There are no commutating contacts, and no clockwork mechanisms or other special means required for determining the rate of travel mechanically of parts of the apparatus. I am quite sure that in connection with the long-distance transmission of power, as well as in the field of telephony, there are a wonderfully large number of problems which it has been absolutely impossible for us to study properly for the want of just such an instrument as Professor Ryan has given us; and for him to have brought this down to an instrument which can be used commercially, not a physical laboratory instrument at all, is to my mind a wonderful achievement on his part. We probably know very little of the energy and time and life that Professor Ryan has put into the development of this instrument, and I am very much inclined to believe that the reason we have not heard more from Professor Ryan in the last few years than we have, is because he has been building up and preparing something for us that is extremely good. It gives me, therefore, great pleasure to offer this resolution.

Resolved, That a vote of thanks of the INSTITUTE be tendered to Professor Ryan for the magnificent wave-tracing instrument which he has devised and which he now presents to the electrical fraternity.

DR. KENNELLY:—I second the motion, Mr. President.

PRESIDENT SCOTT:—You have heard the motion, that we express the appreciation of the INSTITUTE for what Professor Ryan has already done. I think, however, we need not regard this paper as completing the subject, as it gives great promise for the future by presenting a new instrument for research.

(The motion was carried.)

PRESIDENT SCOTT:—Professor Ryan, you have our sincere thanks and appreciation.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 3, 1903

SOME NOTES ON CERTAIN UNDERGROUND HOISTING PROBLEMS ON THE WITWATERSRAND.

BY A. W. K. PEIRCE.

Gold mining on the Witwatersrand consists chiefly of the exploitation of the " Main Reef Series," a bed of gold-bearing conglomerate with an east and west strike, and dipping to the south at a fairly uniform angle in the neighborhood of 30°. For an extent along the strike of some 50 miles this reef series has been proved to be gold-bearing, and the continuity of the deposit has been proved by actual mining and by bore holes to such a depth on the dip that mining ground is held at a high valuation even where the ultimate mining depth cannot be less than 8,000 feet (vertical) or even more.*

The permanence and the uniformity of average dimensions and values of these gold-bearing conglomerates make the mining in this area partake more of the nature of an industrial enterprise than is usually considered app opriate to mining ventures. This justifies the great attention that is paid to the engineering features of the work, and the large sums spent on the necessary mechanical equipment for the rapid and economical mining and reduction of the ore on a large scale.

According to the Transvaal mining laws, only the ore body contained vertically beneath the surface claim area can be mined by any given mining company. In order to exploit the ore contents of a mine situated at a distance from the outcrop, it is the practice, therefore, to sink one or more vertical shafts near the

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*See " An Estimate of the Gold Production and Life of the Main Reef Series, Witwatersrand, Down to 6,000 Feet." By Messrs. T. H. Leggett and F. H. Hatch. Transactions Institute of Mining and Metallurgy. Vol. X (1901-2).

northern boundary of the property, to the intersection of the reef. This is then opened up by horizontal drives in the direction of the strike, and inclines along the dip; the principal inclines, in the most cases, being extensions of the vertical shafts. The ground thus opened up is stopped as required for the reduction plant, the development being kept ahead of these requirements sufficiently to permit of keeping up average values of the output, in spite of local variations in the gold contents of the ore body; and this process is continued until the payable ore body in the claim area is exhausted.

Where these vertical shafts are of moderate depth, the hoisting in both vertical and incline shafts is done by steam winders located on the surface, the vertical shaft being turned through a circular or parabolic curve into the incline. At greater depths, separate winders are used for the two sections (vertical and incline), but both located on the surface, the ropes for the incline hoists being led down the vertical compartments near one side, and suitably guided into the incline, the ore being transferred from one hoist to the other at the intersection of the two shafts.

Further extensions of the "Deep Levels" involve vertical shafts of 3,500 to 5,000 feet to the intersection of the reef, with inclines from this point of 3,000 to 6,000 or more feet in length; and in planning the development and equipment of these new properties, it is evident that persent hoisting methods must be considerably modified. A recent paper by Mr. H. C. Behr* very ably presented the various features of this hoisting problem, and in this paper and the ensuing discussion will be found a very complete treatment of the matter from several points of view.

The concensus of opinion amongst South African engineers seems to be that these "Deep Levels" will be operated on an even larger scale than has obtained previously, the output planned for being 2,000 to 3,000 tons per mine per day; and that the greatest attention will be given to the economics that may be effected in working costs by the use of machinery, and in economic methods of operating the same. The advantages of electric power distribution are well recognized, and this method will be extensively adopted for what may be termed auxiliary power requirements. This is not an inconsiderable amount; it may be from 500 to 1,500 k.w. per mine, for surface requirements only.

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*"Winding Plants for Great Depths." Read before the Institution of Mining and Metallurgy in London, May 15th, 1902, and before the South African Association of Engineers, in Johannesburg, August, 1902.

The underground workings will be arranged with a view to rapid removal of the ore contents, and it is probable that several incline shafts, operated by independent winding engines located underground, will be used to feed each single large vertical shaft, the latter having several pairs of hoisting compartments, and possibly arranged for hoisting in stages. In any case, there will exist within the next few years a demand for hoisting engines of considerable size, to be located underground in a dozen or more of the " Deep Level " mines, and with from three to six hoists per mine.

As in several cases a number of these mines in the same neighborhood are controlled by the same financial interests, and will require their equipment at approximately the same period of time, it is perfectly feasible to consider the supply to such a group of mines of their electric power requirements from a single central power station; and if these requirements are to include the underground hoists I have mentioned, it may be of interest to mention in a general way some of the conditions of the problem thus presented, and some of the conclusions that have been drawn therefrom.

In the first place: The principal power requirements of the mine equipment and the area over which the power is to be distributed (this being several square miles, with an added distance of in the neighborhood of a mile for each transmission to any underground installation) practically determine the use of a polyphase system at a moderately high voltage, especially as the ratio of copper cost to power cost is about twice as great in the Transvaal as in most countries, thus rendering the use of small line losses desirable.

However, I think it is generally conceded that, for hoisting work on the scale indicated, direct current motors are more suitable than alternating. Their use in this instance, therefore, involves apparatus for converting the polyphase supply into direct current.

In spite of the losses and extra first cost involved in this conversion, it presents many important advantages in connection with the control system and the central station supply, as I shall endeavor to show.

First, however, as to the nature of the power demand of such hoists as will be required.

The hoists will be of the double drum type, with clutches for each drum; and while they will be operated normally in balance, they must be capable of bringing up a fully loaded skip from the bottom with the other drum unclutched, *i.e.*, without the balancing effect of the empty skip and its rope.

While for each particular installation the size of the hoists must be separately determined to suit varying local requirements with regard to degree of inclination, load to be hoisted, length of haul, etc., the following may be taken as representing the approximate limits, between which particular values will be taken to suit conditions:

Load of ore 5,500 to 8,000 lbs.

Hoisting speed 2,000 to 3,000 feet per minute.

Degree of inclination 25° to 45°.

A hoist to suit what may be taken as average conditions would demand some 400 k.w. at the end of the acceleration period.

The hoists would be installed for an ultimate hoisting distance of perhaps 3,500 feet along the incline (any longer inclines being equipped for hoisting in stages), but would only have some 300 feet or so to haul when first installed. As the incline would be continued at the rate of about 100 feet per month, in about two and a half years the hoist would be working at its full capacity, and during most of this time would be operating under maximum conditions of load, the variables being the frequency and the duration of the trips, and possibly maximum speed if the control scheme be suitable.

Considering an individual normal trip, it is evident that the maximum torque required from the hoist motor occurs at the time of starting the loaded skip on its upward journey; for the acceleration is a maximum, the moment and friction of the ascending rope is also a maximum, and the balancing effect of the rope on the descending skip is a minimum. On completion of the acceleration period the effective torque still continues to decrease during the remainder of the trip, by reason of the winding up of the rope on the ascending skip and the corresponding unwinding of the rope on the descending skip.

The design of the hoist should not be such that this torque would become negative before the completion of the trip, as this would require the application of the brakes at this point to destroy all the inertia of the moving masses. It is obvious that this inertia should be utilized as far as possible to complete the last part of the trip, the brakes only being used to effect the final landing of the skip.

While similar in kind, the mechanics of this problem are quite different in degree to those of operating elevated railway trains, the relative value of the kinetic energy of the moving masses and the work done against friction and gravity being quite different in the two cases. Thus, with the limitations to hoisting speed imposed by practice, a considerable part of the trip must be made with power after the acceleration is completed, and the " coasting " period only exists for the few seconds required to bring the moving masses to a standstill.

In considering the demand on the generating plant occasioned by such a trip, the form of the acceleration curve to be adopted is of importance.

Obviously if the available acceleration moment is fixed, maintaining the moment at a constant (maximum) value throughout the acceleration period gives a minimum duration of that period; but, as pointed out by Mr. Behr in the paper previosuly referred to, an acceleration showing a constant decrease from the same maximum value to zero will give the same ultimate velocity in a certain space, and requires only 5 per cent. greater time than is needed to cover the same space with the same maximum velocity using an acceleration maintained constant at the maximum value.

The maximum power actually demanded by the hoist motor during a given trip depends upon the form of the acceleration curve, and is materially greater with constant acceleration than with constantly decreasing acceleration. The power demand being proportional to the product of the total torque and the speed at any instant during the period, it is evident that as the constant acceleration maintains the initial maximum torque until the maximum speed is reached, the power demand continually increases during the acceleration period, and at its end is a maximum. With a constantly decreasing acceleration, however, the maximum torque only occurs at minimum speed, and at maximum speed the acceleration torque is zero therefore the maximum power demand occurs at some instant between these two points, and is but little greater than the power demand at full speed after acceleration ceases, which is that required for overcoming the effects of friction and gravity only. The actual amount of the work done is of course practically the same in either case.

It is evident that the constantly decreasing acceleration is much more favorable to the central station, in that it gives a better load factor, less fluctuation in the power demand, and requires less investment in generating plant, provided the method of control is such that the power demand from the source of power is proportional to the actual power demanded by the hoist motor.

The control system is thus the important factor in attempting to realize these advantages, as the *decreasing acceleration* is more normal for electric motor operation than the other; and for this purpose I know of no other method of control that is workable than some form of " voltage control " or " Leonard " system. Involving as this does some separate dynamo machinery for each motor installation, the advantage in control method previously referred to in connection with the conversion from the assumed polyphase distribution to direct current becomes apparent, in that this converter machinery may be utilized in one of a number of obvious ways to furnish the " voltage control " of the hoists.

This machinery also helps out the central station in another way, in that the inertia of its moving parts further smooths out the peaks in the demand curve during each trip; this effect may even be increased by the deliberate addition of inertia to the converter set in the form of a fly wheel, as has been proposed by several Continental engineers that have investigated this problem.*

The " voltage control " also possesses incidental advantages. The necessary slow speed inspection trips in the shaft may be readily made; during the first year or so of operation, the controller can readily be provided with adjustable stops limiting the maximum speed (consequently the maximum power demand) to whatever amount will give the desired output, and thus again improve the central station load factor; the controller need not handle the very considerable main current of the motors, thus eliminating a source of considerable first cost, and also maintenance cost; given positions of the controller handle result in nearly enough given speeds, irrespective of loads. These characteristics are so well known that it is perhaps superfluous to mention them here; I only wish to indicate that in almost every particular this problem is best met by this control scheme, which favorably affects both the source of the power and its utilization.

I have only stated the conditions in a general way, without particular data as to details, for much of the data has not yet been definitely determined, and would necessarily vary with the different local conditions of different mines. I trust that in

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* See " Electric Winding Problems," by Mr. H. Spengel, Transactions South African Association of Engineers, 1902.

spite of this, I have justified to some extent the conclusion that for this important hoisting work, the best method is the combination of polyphase transmission, conversion to direct currents separately for each hoist unit, and the utilization of the conversion machinery for obtaining suitable control of the hoisting operations by the " voltage control " or " Leonard " system.

PRESIDENT SCOTT:—I had the pleasure of meeting Mr. Peirce when he was in America a few years ago, and it is unfortunate that we have not time for discussion of the paper at present, as it is certainly a valuable contribution.

FRIDAY—JULY 3, 1903.

PRESIDENT SCOTT:—The meeting this morning is a joint meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS and the Society for the Promotion of Engineering Education. Professor Woodward, of Washington University, St. Louis, the President of the other Society, is on the platform, and I take pleasure in presenting him to the INSTITUTE.

Part of the papers are contributed this morning by members of the INSTITUTE and part by members of the Society.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls N. Y., July 3, 1903.

THE TEACHING OF PHYSICS TO ENGINEERING STUDENTS.

BY W. S. FRANKLIN.

I have been teaching physics to college and university students for nineteen years and I now have a few ideas on the subject which can, I think, be expressed independently of the subject-matter and which may be helpful to others.

Some time ago, in talking with a practical engineer on the teaching of physics, I stated that in my opinion the ultimate object of the teaching of physics to technical students is to lead the young man by a shortened route to that familiarity with physical things which is possessed by such a man as John Fritz. The shortening of the route which leads to this result depends upon the fact that the teacher of physics has to do largely with an *epitome* of real knowledge, and consequently the primary object of physics teaching is, in my opinion, to develop in the young man's mind a logical structure consisting of the aggregate of physical conceptions and theories.

Since beginning the teaching of physics, I have never devoted any of the time of my classes to the discussion of the history of the subject. The best way to study an organic structure is to study its history, through the medium, say, of embryology, but this is the worst possible way to study a logical structure.

I have never on any occasion apostrophized the Wonders of Nature to any class of mine. The ability to measure electricity and the ability to calculate magnetism are really very simple and prosaic things, and any writer or teacher who for a moment allows himself to speak of these things otherwise than in explanation or in application, may be set down at once as attempting to lend an element of mystery to knowledge he claims to possess. It seems to me a very significant fact that in most of the cases that have come to my notice, the appeal on the part of a scientific writer to the reader's wonder-sentiment has been associated with very hazy, or entirely faulty, notions on the writer's part. I know of a text-book on physics which introduces the discussion of the doctrine of the dissipation of energy in the chapters on Mechanics: this text-book actually would have it appear that the degradation of energy is *essentially the change from the potential to the kinetic form*, and the whole discussion ends as follows: " Tait calls available energy *Entropy*. The inevitable conclusion is that *entropy tends toward a value of zero*. In the beginning, then, points to a period when all energy was available. With no less certainty, physical science points to a time when entropy shall become zero. All the processes of nature must then cease. Even the earth itself, as lifeless as the moon, can no longer circle round the glowing sun, but both and all together, in one dead mass, must hang in everlasting silence in the boundless night of space." Now, what I want you to keep in mind, is that this wonderful view adown the corridors of Time is ostensibly based, in the book in question, upon a succession of egregious blunders.

I never have allowed the slightest speculative tendency to enter into any of my teaching, oral or written, and the extent to which many of our elementary text-books in physics indulge in imaginative nonsense and in weak phases of speculative philosophy is distressing to me. Nearly every text-book on physics that I know of defines the mass of a body as "the quantity of matter the body contains." I had the pleasure thirteen years ago of listening to a course of lectures by von Helmholtz on theoretical physics, and the first eight weeks or more of this course was devoted to the origin and meaning of our quantitative methods in physics. I thought at the time that von Helmholtz's statements were so simple and so apparently remote from the usual complications of physics that most of his hearers were likely not to appreciate what he said. Those lectures, however, stand in my mind as the most complete outline of the philosophy of the mathematical sciences ever given. All our notions of length and angle arise from and are defined by the fundamental geometric *operation* of congruence. The definition of mass, likewise, is a *physical operation*, the verbal definition is the briefest possible specification of this operation. The result of this operation on a given body is an invariant number, and by a feat of the imagination we are led to adopt this number as a measure of the "amount of matter the body contains." This is a notion of some mental utility although strictly it is mere imaginative nonsense. Several years ago I had occasion to review a well-known French book on "Electrical Measurements," the authors of which say "Une grandeur est une quantité susceptible d'augmentation ou de diminution. Une grandeur est dite mesurable quand on peut la comparer à une grandeur de méme espece et qut la résultat de la comparison donne à notre esprit une satisfaction complète."

As an example of weak speculation, what do you think of the use in a *secondary school book* on physics of the following quotation from Maxwell as a means to clear up an inadequate discussion of energy? "We are acquainted with matter only as that which may have energy imparted to it from other matter, and which may in its turn communicate its energy to other matter. Energy, on the other hand, we know only as that which in all natural phenomena is continually passing from one portion of matter to another." What do you think of the following from an elementary English text-book on physics? "The fundamental property of matter, which distinguishes it from the only other real thing in the universe, is inertia. * * * We are now in a position to give one or two provisional definitions of matter—provisional because we cannot yet say, possibly may never be able to say, what matter really is. It may be defined in terms of any of its distinctive characteristics. We may say that matter is that which possesses inertia, or again since we have no knowledge of energy except in association with matter, we may assert that matter is the Vehicle of Energy." I wonder if any of you really doubt that every notion in physics, definite or indefinite, is associated with and derived from a physical operation, and that absolutely the only way to teach physics to young men is to direct their attention to that *marvelous series of determining operations which bring to light those one-to-one-correspondences which constitute the abstract facts of physical science.* If you do doubt this, I am bound to say that I do not think much of your knowledge of physics. I think that the sickliest notion of physics, even if a student gets it, is that it is the "science of masses, molecules and the ether." And I think that the healthiest notion, even if a student does not wholly get it, is that physics is the science of the ways of taking hold of bodies and pushing them; that it is the aggregate of all things that can be "by handling known."

In my opinion, the characteristic feature of science study, especially of the study of physical science, is *a determining objective constraint upon the processes of the mind.* I am surprised that this one important feature of science study is never mentioned in the many estimates that have been made of the value of science study in education, for as a matter of fact, that *complete definiteness* which is usually urged as the characteristic and valuable feature of science study is the fundamental condition of every psychological process, you say this or you say that, you go or you do not go, and even the classic mule standing midway between two similar loads of hay is in no danger of starving from indetermination. The psychological processes which are brought into play in the study of science do not differ from other psychological processes in regard to definiteness.

I say again that it is the completeness of objective constraint that chiefly differentiates the study of the physical sciences from all other studies and which makes the study of the physical sciences so important an element in any correct scheme of education. The importance of this objective constraint upon the mental processes in scientific work is most strikingly shown by the entire absence of any such constraint in all of our crank scientific literature. I think that the full realization of this objective constraint in the teaching of physics depends first of all upon the making of one's teaching utterly and absolutely simple and homely, *and devoid of all appeal to anything but the rigors of the scientific imagination.* Anything beyond this is, in my opinion, idolatry.

I think that the ability to learn science by reading is a highly specialized faculty and that among average young men this faculty is nearly zero. I know many men who are quick to receive knowledge by experience, and quick to catch, from verbal description, manifold variations of their empirical knowledge, but whose imagination is wholly unresponsive to that abstract kind of writing which is so necessary in a concise treatise on the elements of physics.

Nevertheless, I think that the development of the student's imagination to the extent that is necessary to enable him to follow concise writing is one of the chief objects in the teaching of physics, and I do not believe that this result can be accomplished without requiring the student to use a text-book of the severest kind.

My idea of the teaching of physics is to use a sharply, clearly and concisely written text-book, to give explanatory lectures of such character as to appeal properly to the student's imagination (*theoretical lectures*, in fact, illustrated by the simplest kind of experiments), to require of the student a large amount of numerical calculation, and to give a laboratory course based upon highly generalized printed directions supplemented by a vanishing series of verbal suggestions from an instructor.

I think that the chief object in a course in physics for technical students should be to give conceptual and analytical knowledge of the most important facts of physics. It is certainly better to know a little by reason, than much by rote. There is nothing in the teaching of physics so important as to develop in the student the ability to express physical conditions in mathematical form, geometrical or algebraic as the case may be, to reproduce or re-present the conditions of a problem adequately as a geometrical construction or as an algebraic formula. Nothing, I think, is so important as this for technical students. It is the very essence of effective knowledge of physics, and every bit of attempted instruction in physics which does not contribute directly or indirectly to facility in this re-presentation of physical fact in terms of our mental tools is in my opinion futile.

Many students, and even teachers of physics raise the objection that a rigorous mathematical presentation of physics is highly unsatisfactory and uninstructive. They like such a book as the excellent new book of Edser's on *Light* which abounds in descriptions of phenomena and of the most recent researches on light pressure and the cause of comet's tails. Now, I am really interested myself in comet's tails, but I would feel like thrashing a young student who concerned himself about comets' tails but held his imagination unresponsive to a discussion of stationary wave trains and of reflection with and without change of phase. I have a contempt for a student who thinks he understands the formation of a comet's tail but admits that such things as the kinematics of wave motion are beyond him. I recommend such a student to be honest with himself and study physics under the instruction of Jules Verne. Then he need not trouble himself about foundations, but he may follow his teacher pleasantly on a careless trip to the moon and with easy improvidence embark on a voyage of ten thousand leagues under the sea.

In my teaching of physics I have come to distinguish two distinct phases of laboratory work. One phase is that which is intended primarily to vivify algebraic formulas—I think it is silly to talk of the verification of Nature's Laws(!) by a student—and the other phase of laboratory work consists of elaborate and precise measurements carried out with every possible precaution for the elimination of error.

I take pleasure in distributing to the INSTITUTE members here present a small pamphlet which I have had printed for this occasion as an illustration of the vivifying phase of laboratory work. The eight experiments described in this pamphlet apply to the direct current dynamo, and I think that every technical student who studies physics to any extent should perform these experiments just to see the equations of the dynamo become alive. No one really knows much physics who is not able to look at an equation and see the manifold activities which the equation is intended to represent.

DISCUSSION.

PRESIDENT SCOTT:—The paper of Professor Franklin, which presents the subject of teaching physics in a manner that is certainly quite different from the old idea, is now open for general discussion.

PROFESSOR GOLDSBOROUGH:—If I catch Professor Franklin's idea correctly, what he means is that the boys should have a thorough and complete drill in theoretical electricity and then they should be taught to apply that theoretical training in practical work, and not be sent out of college with a theoretical training and a practical training which to the student have no relation the one to the other. Referring to what Professor Franklin says as to the equations of the dynamo, why, there are lots and lots of young men who know the equations of the dynamo and who know the equations of alternating current circuits, but there are comparatively few who feel thoroughly acquainted with them; they know them in a vague kind of way, but their ideas are involved and not made a part of themselves. Too much care cannot be taken to have students pass into professional life with the proper " joint " between the theoretical and the practical. This requires skill on the part of the instructor in putting the student through the right " soaking " process. It is a perfect farce for us to introduce empirical formulas into electrical engineering. There is hardly a problem which we cannot solve with the use of a rational formula. Students very frequently come to me who have had training in certain mechanical subjects in which it is absolutely necessary to make use of empirical formulas. They then want to jump to the last formula on the page, which shows the result, and " substitute " in that formula. I always make them go right back to the beginning, to the start and go right down through, until they get what has gone before, and until they master this I do not think they have any business discussing the result.

PROFESSOR LANGSDORF:—My own experience in teaching dynamo laboratory work is not quite so long as that of Professor Franklin, but it has been long enough to show me that there are two ways of conducting the work. One method is to give the student at the beginning the equation which represents the relation between the quantities which he is to measure, and then have him verify it by substituting therein the numerical data obtained in the laboratory. The other method is to give him the apparatus, tell him to take the data, plot his curve, and then finally determine the equation from the curve.

I think that by the latter method the thing is impressed upon the student as it can be done in no other way. I remember that in my own experience as a student, when I had to derive the complete equation of the bifilar pendulum, it took on a meaning which blind acceptance could not have given to it; and it is this method which I have always used with my students.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 3, 1903.

THE PROBLEMS THAT ARE FACING THE ELECTRICAL ENGINEER OF TO-DAY AND THE QUALITIES OF MIND AND CHARACTER WHICH ARE NEEDED TO MEET THEM.

BY J. G. WHITE.

Since the title assigned for this paper contains more than one per cent. of the total number of words allotted, there seems little room to speculate as to the problems confronting us.

To some engineers apparently the one and only problem is that of salary, while for others the greatest problem is to find men who *can* and *will* earn large salaries.

Other problems range from figuring the proper size of an electrical conductor or tracing out a telephone circuit up to the highest speculative imaginings of which the human mind is capable, such as those suggested by the recent statements of Prof. Crooke's, Prof. and Madame Curie and others, regarding the atomic theory.

We are now told that each atom, formerly considered indivisible, is a whole stellar system, composed of a tremendous number of absolutely identical units, all in orbital motion.

We are further told that of these identical units or ions, an atom of oxygen contains 11,200; an atom of gold 137,200; an atom of radium, 120,000; and so on.

Who can delineate the problems which will be presented by this new theory, or by the strange properties of the recently discovered radium and other radioactive substances?

A recent article on this new development says: " Chemistry has in fact become the astronomy of the infinitesimal. One is led to wonder then if the earth and the other planets are not mere ions forming a single atom of a higher universe, where perhaps they constitute a speck of dust that worries the careful housewife in the world next above us."

As, however, this is a body of educators and engineers rather than of astronomers and philosophers, may it not be well to avoid speculation and be content during the brief time at our disposal with what might be called a " plain 3 per cent. investment? "

The qualities of mind and of character needed by the electrical engineer of to-day are too well-known to need to be specified.

He should be *accurate* in his calculations, *thorough* in his investigations, *logical* in his deductions, *lucid* and *concise* in his statements.

He should have *untiring energy*, an *alert mind*, abundant initiative, and *reasonable self-confidence*.

He should be absolutely *honest* in all his dealings, *truthful* in all statements, *loyal* to his clients, *faithful* to his employer's interests, *considerate* of his subordinates, *diplomatic* in his negotiations and *tactful* in all his relations.

However, instead of attempting to rear a structure on the foundation of the text assigned to us, may we not rather use it as a spring-board from which to vault into the general field under discussion to-day?

This might be summarized under the title, " What education should the electrical engineer of to-day have."

In entering this field, I realize that I may be trespassing on the preserves and vested rights of Messrs. Gherardi, Osborne and Johnston, whose papers are to follow:

In that case I hope these gentlemen will follow the example of the beasts in Kipling's Jungle Stories, and wish me " Good Hunting."

Irrespective of this, there are a few points in the education of an engineer which are so important that it would probably do no harm if they should be repeated and urged by every one of the men to whom papers for to-day's session were assigned.

One of these points is well covered by Mr. Johnston's paper, " Engineering English," the great importance of which is further emphasized in the latter part of this paper.

As is frequently remarked, this is the age of great industrial combinations and of specialists. Not satisfied with this, the specialists now specialize. The engineering field was formerly divided into the two general classes of military and civil engineers. From the latter gradually developed marine, mining and mechanical engineering, and as an offshoot from this last branch, there was recently added electrical engineering. Civil engineers to-day are sub-divided into such classes as hydraulic engineers, bridge engineers, railroad engineers, etc. We also find that electrical engineers are classified as telegraph engineers, electric light engineers, electrochemical engineers, telephone engineers, etc.

A few years ago many of us would have supposed that the problems of the telephone engineer were those of a high-class artisan and that they would consist largely of trying to unravel tangled cobwebs of fine wires, and to understand and to be able to operate mazes of signalling, connecting and protecting devices. A member of the INSTITUTE OF ELECTRICAL ENGINEERS, who is the head of the electrical engineering school in a prominent university, remarked not long ago that he never appreciated the importance of the telephone engineer until he saw one of the particularly well-known members of the profession decline a salary of $25,000 a year. The professor further stated that ever since then he has wished he knew enough to be a telephone engineer.

In the early days it was thought that a room of almost any shape and size, with a couple of empty boxes for seats, and a switchboard of primitive design and construction was all that was needed to make a telephone exchange. The City of New York had in 1894 about 10,000 telephones or "stations"; in 1900 the number was about 45,000; at present, the number is in the neighborhood of 100,000, an increase of 1,000 per cent. in nine years, and by 1910 it is estimated the number will be perhaps 300,000. These figures are understood to be exclusive of desk or other extension sets.

Owing to the wonderful growth of their business, telephone companies now erect buildings specially designed to meet the requirements of their exchanges, and a telephone engineer must know something of architecture, the strength of materials and other factors entering into modern steel building construction, and many other subjects which should be a part of a broad engineering education, but which are not ordinarily supposed to come within the province of a telephone engineer, as narrowly applied:

It is at least equally important that other engineers who have specialized and must know well some part of the field of engineering should likewise have a general knowledge of the sciences and of the broad underlying principles of engineering, based on a thorough mastery of elementary mathematics and supplemented by some study of languages, history, civics and other studies of general educational value.

The question naturally arises, how can the engineering student possibly obtain a satisfactory knowledge of all of these important subjects? Much of his special knowledge must be acquired after he has commenced the practice of his profession. If unusually energetic and capable, all or any part of his education may be gained after he enters professional life, but it is preferable that his broader education be well started during his school years. For a considerable time it has been clearly recognized that law and medicine require, for general and special study, more time than is possibly available in the ordinary college course of four years. The well-educated lawyer of to-day takes a thorough preparatory course, four years in college, and three, or at least two, years in law school, and after this is likely, if he can afford it, to take one year abroad or in some special post-graduate work. The well-educated physician of to-day after regular and preparatory courses, spends three years in medical college, and if possible, one year in foreign study, and then is likely to devote several years to hospital work, before attempting to engage in the general practice of his profession.

If lawyers and doctors can afford the time and money necessary to get such educations, should not engineers, in view of the very wide range of subjects with which they must now be reasonably familiar, adopt a similar plan? The decision of the question will have to be made individually by the young men themselves, important factors being the time and money available for educational purposes.

It is well to remember, however, that more important than a knowledge of any study, or group of studies, is the ability to master *thoroughly* any subject of which a knowledge is desired.

In education especially, quality is more important than quantity. A thorough mastery of arithmetic and algebra is better than a mere " pass grade " knowledge of these and all the higher mathematics, which is then ordinarily soon forgotten.

It is better never to have seen the inside of a Latin, French or German grammar, and to use correct English, than to have the ordinary three or four years " translating knowledge " of all three of these foreign languages and still say " I seen."

As in nearly all practical engineering problems, this one of engineering education can perhaps be best set forth by arranging a balance sheet showing the credit and debit sides. Against the extended education we have expense involved, time necessary before the earning period is reached, time required for general study which might be devoted to mastering some special branch of engineering, thus more quickly insuring a comfortable salary, danger to health if too much study is crowded into a given period, etc. On this side also we have the danger that by widely extending the field of endeavor we may produce a student rather than an engineer, or that the work may be superficial. The *importance of thoroughness is supreme.*

This implies also that the education of the engineer must develop not a dreamer, but a worker, thoroughly competent in his sphere, whether great or small.

It is better for the world and for the man that he should be a high class mechanic or artisan, with a good common school education, than that he should be nominally an " engineer," having a smattering of many subjects, and ekeing out an existence amongst more competent fellows.

It is better for him never to have been inside a college, but to have commenced at wheeling ashes and become a good electric light superintendent, than that he should " drag " through college and university, take master's and doctor's degrees and become an incompetent college professor. His social status may not be as high, but he will be a more useful man.

On the credit side of the extended education we have, first, the direct satisfaction to be had from its possession and the ability to enjoy on even terms the society of educated people.

Secondly, there is the practical use to which this knowledge can be put.

Thirdly, and more important than the knowledge actually acquired, is the learning how to *know a subject,* and where or in what direction to look for information specifically wanted.

Fourthly, there is the certainty that with equal industry and attention to his work, the young engineer of ability with a broad education will ultimately take higher rank in his profession and be more successful in business.

The qualified phrase, " young engineer of ability " is used advisedly. The engineer of ordinary or less than ordinary ability, will, in practical life, accomplish most by not attempting to have his education cover too wide a field, and learning some special department thoroughly.

A prosperous market gardener is more to be envied than a poor farmer.

If a young man will take for his motto " thoroughness," and, in planning his list of studies, will include first those of prime importance, and then add those of decreasing importance until all his available time is occupied he will be planning most wisely. Ordinarily the young man will not be able to arrange a course entirely to suit his individual requirements, but he can use the method above suggested to help him in deciding as between various courses offered. The choice should, when time and mental capacity make it possible, be in favor of a broad general education, supplemented by thorough technical training. This may, and frequently will, lead to a general college course to be followed by a technical course of two or more years.

The writer recently knew of two groups of men who were each looking for an able street railway manager, and who were willing to pay in each instance a salary of $25,000 per annum. The man who happened to be offered both of these positions is said to have been for 12 years a street car conductor. This is no proof that an engineering education is valueless. It is, however, conclusive proof of the *superior importance* of *good business judgment* and the ability *thoroughly to master a given subject*, which in this instance happened to be street railway operation and management.

People are to-day looking for engineers and would gladly pay salaries of $6,000 to $10,000 per annum for men of exactly the right qualifications. It would be easy to find hundreds of men who have had all the necessary general education, and scores who have had as well all the needed technical training. The questions which are asked, however, are such as the following:

Has he good business judgment?
Has he tact?
Has he the mental capacity and breadth to develop into a "big man?"
Is he diplomatic, with ability to negotiate?
Is he initiative, without being erratic?
Will he get results?

We might divide the studies which are worthy the attention of the electrical engineer into four general classes. Individual opinions will necessarily differ widely as to the studies which should come within each class. Some will want to increase and others diminish the total number. In any event, the student should attempt studies of the relatively less important classes only in case he has already mastered thoroughly, or is sure of so mastering, the more important studies.

In the first class we may put those studies which will teach to *think clearly* and *express lucidly*, which will *teach how to learn*, and which will give a comprehensive knowledge of the fundamental facts and principles underlying his profession. These should be learned most thoroughly, and would include English, arithmetic (*mental* and written), algebra, geometry and trigonometry, chemistry, physics (especially mechanics), general knowledge of principles of electrical engineering, practical ethics.

The second class may include *some subjects* which will especially tend further to develop clear thinking and clear writing, some which will further increase the knowledge of the general principles of his profession, and some which will give knowledge that will be professionally and commercially useful. This class includes: Calculus and vectors, surveying, Latin (usual preparatory course) French (speaking and reading—not translating knowledge of), electrochemistry, advanced engineering studies, business law, general principles of modern accounting, civics.

The third class may include some subjects which are likely to be of direct professional or commercial use, and others, the study of which will be of general educational value. This class includes: Spanish, geology, physiology and temporary care of injured; logic, quaternions and subjects which are studies of engineering details rather than of general principles, etc.

The fourth class may include those studies which will help in rounding out the education of the man rather than in furnishing the essential equipment of the engineer. This class includes: Mineralogy, botany, zoology, history, political economy, mental and moral philosophy, art, music, etc.

The third and fourth classes of subjects are useful to round out and complete the foundation and frame work provided by the first and second classes, but should not be indulged in at the expense of the relatively more important. A few non-technical subjects merit individual mention.

ENGLISH.

President Butler, of Columbia University, is reported to have said: " The first two evidences of an education are correctness and precision of speech, and refined and gentle manners." The latter must be acquired almost entirely at one's home and from contact with one's associates. The correct speech must be acquired largely in the same way, but may be learned to a considerable extent, in the preparatory schools and in the college or university. There is nothing more important for the young engineer to learn than " the skilful and correct use of language, whether to state a fact or convey an idea," understanding that " clear thinking precedes clear speaking."

English should be taught from beginning to end of the preparatory school work, and also from beginning to end of the college course. In order to have this drill continue throughout the college course, it may be necessary to have a considerable part of the training incorporated into the writing of *laboratory reports*, *examination papers* and other similar documents. Is this not feasible? Whether done in this way or not, the training should be continuously maintained.

ARITHMETIC AND ALGEBRA.

More attention may well be paid in the preparatory schools to algebra and arithmetic, especially *mental* arithmetic. A comprehensive understanding of algebra is most useful to the engineer both in his later studies and in practical work. Mental arithmetic provides both good mental exercise and equipment.

We sometimes hear engineers, as well as others, speak of the "poetry of motion." Many of our profession seem to understand this, only as applied to the slide rule. It is unnecessary, and is frequently annoying to have an engineer who is drawing a salary of several thousand dollars per annum pull out his slide rule, and, after some considerable manœuvring, announce that "5 times 4½ is about 22," or that "two tons of rails at $33 per ton will cost *about* $65."

SURVEYING.

During the college course it would seem advantageous even for the electrical engineer to devote a moderate amount of time to the study of the various methods of surveying now practised. These can be quickly understood if the student has thoroughly mastered his arithmetic, geometry and trigonometry, and a general knowledge of surveying is very likely to be useful in practical work. The summer spent on railroad location and construction will help develop one's physique, teach one to read and fully appreciate a profile, give a little knowledge of construction costs and methods, and give other knowledge which one will probably find useful in both field and office. A summer so spent will in after life be remembered as time well and profitably occupied.

FRENCH AND LATIN.

French and Latin are included in the second class, because of the mental training and polish to be gained by their study. Some knowledge of Latin will greatly assist in thoroughly mastering English, and is in this respect more useful than the study of German.

A knowledge of French which will enable the young engineer to speak and read with ease is strongly recommended. The educated people of Mexico, South America, Russia and other countries speak French, and as this for centuries has been the polite and diplomatic language of the world, the advantages to be derived from mastering it are likely to be not only educational and social, but commercial as well.

On the contrary, there is little prospect that American engineers can practise their profession profitably in Germany or German-speaking countries. Nearly all important scientific papers are now promptly translated into English, and included in the technical press or publications of the various scientific and engineering societies. In consequence, there is no longer any special need of the engineer knowing any foreign languages for the sake of keeping advised as to the progress made in the work of his profession.

The general educational value of learning one modern language seems about equal to that to be gained from learning another. Consequently, the social and commercial advantages of French give it first place for the American engineer.

SPANISH.

The study of a second modern language should be undertaken only in case the first can be spoken fluently. Then it would seem that Spanish is the best language to learn. Having studied Latin and French, Spanish should be very easily acquired.

The development of Porto Rico, Cuba, the Philippines, Mexico, the Central and South American countries, will probably afford many opportunities for the engineers of the coming generation, and to these a knowledge of Spanish would be of great value.

ENGINEERING STUDIES.

The time devoted to various engineering studies in Class 1, as well as in Class 2, must depend largely on the facilities of the college attended, and the special work for which it is intended to prepare. It would be quite useless to attempt to discuss the relative importance of the purely technical studies in the time at our disposal, or to attempt to arrange any detailed plan of technical work.

BUSINESS TRAINING.

Somewhere in the general course there should be included a moderate amount of training in modern business methods and practices. There is no more reason for the engineering graduate being utterly ignorant of even the most elementary knowledge of business practices than that he should know absolutely nothing of geography.

ACCOUNTING.

All engineering students should have some reasonable training in accounting, so that they would not be entirely ignorant and without power of speech if, after beginning the practice of their profession, they are asked some elementary questions about the annual report of a street railway, electric light or manufacturing company.

BUSINESS LAW.

A moderate amount of time should also be devoted to the study of fundamental principles of business and corporation law. An engineer, in practice, should at least be able to draw a contract which will be legal and explicit.

IN GENERAL.

A modern engineer is dependent for his success largely on the financier. If the engineer does not know that bonds should pay interest, and that stocks, if possible, should pay dividends and has no conception of the difference between a stock certificate and a promissory note, the financier is likely to form an undeservedly low opinion of the engineer's technical knowledge.

If a young engiener will have before him constantly the ultimate and best interests of his employer, will endeavor always to be tactful and never unnecessarily to irritate, will—without flattery—say only what is pleasant, unless right demands a plain statement of an unpleasant truth, then his advance will surely be more rapid than if these things are forgotten or neglected. The importance of these things should be pointed out and frequently emphasized by educators.

The techincal problems which face the engineer are certain to be recognized as they come up. Too frequently the importance of problems connected with one's business and social relations with employers, fellow employees and others are not appreciated. These deserve careful and persistent study. Their correct solution and an accurate appreciation of the proper proportion of things, constitute business sagacity. The paramount importance of such matters should be repeatedly impressed on students and they should be led to understand thoroughly that their satisfactory solution will be rewarded not only by a pleasanter life during working hours, but also by increased esteem and greater business success.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 3, 1903.

THE PROPER QUALIFICATIONS OF ELECTRICAL ENGINEERING SCHOOL GRADUATES FROM THE TELEPHONE ENGINEER'S STANDPOINT.

BY BANCROFT GHERARDI, JR.

I have been asked by the Chairman of the Papers Committee to say a few words on the proper qualifications of electrical engineering school graduates, judging them from the point of view of the telephone engineer.

These qualifications are the product of two factors: the natural ability of the man himself and the training which he receives at the engineering school.

Upon the man's natural ability, although a factor of prime importance, I will not, owing to the limitations of time, attempt to speak in detail here to-day. In general terms the nature of these natural qualifications, which seem to me to be requisite in the engineering student, is evident from a consideration of the training which the school attempts to give him, for if he is to obtain anything of value from his school training, he must have those qualities of mind necessary to enable him to assimilate it.

In treating my topic, I shall confine myself to a discussion of the subject of education considered not primarily with reference to preparing the student for his general responsibilities with reference to society, but solely as providing him with the special qualifications needed in his professional work.

In thus excluding from the present consideration the question of what education should be given to the student for other reasons than to fit him for the special work of his profession, I do not wish to belittle the very great importance of broadening studies. A discussion including this phase of engineering education would extend my remarks beyond the time assigned to me, would develop age-long controversies and would, perhaps, after all, be more suitable for discussion elsewhere than at this meeting. Even that branch of the subject to which I have restricted myself is so extensive that it will be impossible here to treat of it exhaustively and at best I will only be able to bring out a few ideas which have impressed themselves upon me as being worthy of serious consideration.

It is well recognized that telephone engineering is one of those specialties into which electrical engineering in general is rapidly splitting, and in consequence of this fact, it has been assumed by some that the school training for the telephone engineer should be different from that given to electrical engineers in other branches. That the telephone engineer should receive at the engineering school a training substantially different from that given to electrical engineers in other branches is a proposition with which I do not altogether agree.

While the professional work required of the telephone engineer, comprehensive though it is, bringing him in contact with various practical problems which do not confront electrical engineers in other branches, his work is, after all, based upon the essential principles which underlie the work of all of those engaged in the electrical engineering profession. It deals with the same materials and the same physical laws and it has the same general object in view; that is, to accomplish the most satisfactory results in the most economical manner.

If, in the few short years which are available for the professional training of the student, it were possible to teach everything in science and engineering which might be available in his professional work, it might then be reasonable to incorporate as a part of such training a large amount of work on problems particularly concerning the telephone plant and the questions which arise in the construction and operation thereof. It is evident, however, that to include in the curriculum such a course of training would far transcend the limits of time which the student can spend at the engineering school. It seems to me, therefore, that instead of attempting to teach these ultimate practical problems, the important matter is that engineering students should have discipline in the methods of solving engineering questions. Such discipline as I have in mind is not given by teaching him the solution of each and every question that may raise in practice, even if the time available would make this possible. On the contrary, this discipline can best be given to him by a general training which will enable him to solve any question that may arise when he becomes acquainted with the conditions of that special problem. When the special problem comes before him, he will, with the proper training, be able to solve it first by getting the facts in the case and then by interpreting these facts according to correct processes of reasoning.

In my mind, therefore, the functions of technical education may be summed up as follows: Train the student so as to convince him of the necessity of getting his facts and teach him the best method of getting the facts. Train him as to the methods of interpreting engineering data and in reasoning thereupon. You will note that I do not say that the education should teach a man the facts. It seems to me it is evident to anyone who considers the question, that no course of college or university education can teach a man the facts and practices of such a field of engineering as we have under consideration. I do not refer to fundamental facts and laws, but refer to the details of superstructure with which so many special courses endeavor to familiarize a man before he starts on his professional career.

The state of the art in the case of any branch of engineering is necessarily voluminous and involved and is constantly undergoing rapid changes. The mere acquiring of such voluminous data and ascertaining their correct relations to other data is the work of a lifetime, even assuming that such data were available in a form which would permit of their being taught in a college or university. Furthermore, and what is more important, the attempt at teaching such data in the length of time available necessarily results in the neglect of those fundamental and general studies, the importance of which I am endeavoring to bring out.

If I were to consider the extent to which broadening or liberal studies should be required of the student, the question of how much time should be devoted to English literature, to logic and to philosophy, would require most careful consideration, but upon one point which might properly come under the head both of broadening studies and special technical equipment I have firm convictions. I shall speak of it here merely as part of the technical equipment of the student.

I am satisfied that extraordinary efforts should be made to teach every engineering student to write a report or letter in clear, convincing English, setting forth the facts and arguments and conclusions pertaining to any question he may have to consider. The student should be taught to state in correct and logical form the nature of any given problem and to enforce his conclusion with arguments which must be convincing. Such training as this is not one merely in literature, composition or rhetoric; for it should be borne in mind that to write such a report as I have indicated, the student must, first of all, have mastered the problem itself, and that clear thinking must precede clear writing.

From this point of view discipline in English is not to be regarded as producing mere literary polish, but as enforcing correct thinking in regard to each and every question upon which he has to write. If rigidly applied throughout all of his college course, this will do more than any other single form of discipline to develop correct habits of thought.

In mathematics the usual training leading up to and including the calculus is sufficient for general engineering work in telephony although it is well for men having special aptitude in mathematics to carry their work sufficiently far so as to be able to handle problems involving differential equations. The relatively small number of questions in practice, however, demanding this knowledge of higher mathematics, does not justify requiring it of every graduate, particularly as those not having aptitude for it would not be able to make much use of it in practice. A student should receive a good training in elementary physics and analytical mechanics, and should be familiar with the application of analytical mechanics to engineering problems. In electricity, the student's work should of course be carried much further than in the other branches of physics, and he should have a thorough knowledge of both direct and alternating currents. In addition to giving him this knowledge in the abstract form it should also be taught in some of its principal applications to the several branches of electrical engineering.

In experimental laboratory work he should have a fair amount of experience. This laboratory work should be chosen primarily as illustrating and proving fundamental laws and also as giving the student the necessary manual dexterity needed in handling instruments of precision. As an important part of such experimental work, I suggest that all electrical engineering students should be thoroughly drilled, not only in general electrical testing, but in the special electrical testing of cables and wires, having regard to their dielectric resistance and electrostatic capacity, as well as to their dielectric strength and other essential physical and electrical properties. Such experimental work should also include some fundamental tests of prime movers as well as standard tests upon generators, motors, transformers and primary and storage batteries.

In the time allotted for this laboratory work, a due proportion should be set aside for selected experiments relating to the telegraph and the telephone. The student should also receive a general knowledge of the materials used in engineering work, both from instruction and from laboratory tests.

In the matter of shop practice, I think it is easy to run to excess. A certain amount of practical experience in shop work should be given to the student so as to familiarize him in a general way with various classes of shop practice. The effort here should be not to make the student a skilled workman, but rather to give him such respectful familiarity with the problems of the workshop that he will have a just regard for their possibilities and limitations. He should be so trained that when in his professional work he is brought into contact with the shop foreman, he will be able successfully to coöperate with him.

One or more foreign languages, and drafting, are everywhere recognized as standard requirements of an engineering education and should not be neglected in the course under consideration.

It does not seem to me that any engineering education is complete without a certain amount of knowledge in regard to legal questions, particularly those relating to the legal responsibilities of engineers, to the execution of work under contract, and to the matter of patents. Nothing, of course, should be undertaken at the engineering school in the way of attempting to give to the student such a knowledge as will enable him to dispense with legal advice upon such questions, but he should be provided with sufficient knowledge to enable him to know when to seek legal advice and to be able to lay his case before the lawyers and to give to them all of the facts which are essential to the proper consideration of the question which may have arisen.

While I have laid stress upon the necessity of a preponderance of fundamental studies in the electrical engineering schools and have argued against the tendency to multiply subjects of study by introducing excessive numbers of courses dealing with the details of engineering questions, I do not by any means wish to be understood as desiring to exclude altogether from the studies a goodly number of examples from practice. I would use the examples from practice, however, as illustrating the fundamental laws and as showing how apparently remote scientific principles are really of the utmost importance in the solution of practical problems.

In choosing the practical examples with which to illustrate a given fundamental principle, care should be taken to select one or more cases from each branch of electrical engineering to which the fundamental principle may apply. In this way the value of the principle will be borne in upon the mind of the student. It will help him to see theory and practice in the proper perspective, and if the examples are well chosen and judiciously placed before the student, they will aid him in deciding upon the particular branch of electrical engineering for which he is best fitted.

At the same time these practical examples, although they may be relatively few in number, will, if adequately treated, not be without some immediate practical value in the student's early professional work.

If the attempt to teach practice is thus restricted, it will, in my judgment, give the desired balance to the theoretical training and go as far as the college should attempt to go in fitting the student for his practical work after graduation.

The Papers Committee have asked me to include in my remarks any criticisms that might occur to me as a result of my experience with technical school graduates. In complying with their request, there are two or three points which I wish to emphasize.

In the first place, many graduates do not seem to appreciate sufficiently that engineering is the determination of the most economical way of accomplishing a desired result. In too many cases they feel that they have done all that is required when they have determined one way of accomplishing a result, and as soon as they have found that way, deem that the question before them is answered.

This state of mind upon the part of a student who has recently graduated and who has never felt the burden of final responsibility is not unnatural, considering the conditions under which his work has been done at college. There, while he may have been taught to look carefully for the most economical solution of a given problem, he could not from the nature of the case be confronted with the severe penalty which falls to a professional man who has failed to obtain the most economical answer to an engineering problem involving large sums of money. The importance, therefore, of earnestly and fairly considering all possible solutions of the problem in hand should be continually impressed upon the mind of the student.

Many instances have arisen in my experience which lead me to believe that notwithstanding all that is said upon the subject, not a sufficient amount of emphasis is laid upon accuracy. I have often noticed that beginners in engineering seem to feel that an arithmatical error in their work, or an inadvertant making use of one figure when they should have used another, or carelessness in getting together their data, are comparatively trivial mistakes, while the use of incorrect mental processes in endeavoring to attain to result is the only kind of mistake which would be regarded as serious.

Without in any sense condoning the use of incorrect mental processes, I wish to point out that as far as practical results are concerned, errors of the one kind are quite as serious, and render the result of as little value as do errors of the other kind. As a matter of fact, these clerical and arithmetical errors are often more serious in their consequences than errors of logic. Errors of logic can readily be determined by a comparatively brief examination of a subject by a competent chief engineer, whereas errors in computation and clerical errors cannot be discovered without going over in full detail the entire work of the subordinate. No qualities of mind, therefore, however admirable they may be in themselves, are sufficient to compensate for this class or errors which I am now condemning. It would have a very wholesome effect, therefore, in dealing with these errors which are so often condoned in the student's college work, if the instructor would force upon the attention of the student the necessity for accuracy in this respect, and point out to him the unfortuante results upon his future career which such errors would produce if they occurred in his professional work after graduation.

Cases have often come under my observation which show that graduates have too little appreciation of the relations between their theoretical knowledge and practice. They seem to feel that practice is a matter altogether apart from theory, and have no physical conception of what corresponds in nature to their theoretical information. This, no doubt, is in some cases due to a lack of ability on the part of the student to grasp and comprehend his theory, and in such cases the defect cannot be overcome by any amount of training. In too many cases, however, I feel that it is partly or altogether the result of the training which the student received in the technical school. This defective method of training might be illustrated by a course of laboratory experiments carefully laid out and described in a text-book with which the student is supplied. Specially prepared apparatus might be set up and wired permanently to one or more set switchboards in the laboratory in such a way that the student might, with a minimum of thought and effort, and by following his text-book, which carefully describes the experiment, go through the form of making the tests, carefully entering the results of each test upon printed forms, kindly prepared in advance for him and having upon them a space in which to enter the result of each observation. For a student working under such paternal conditions, it would be well-nigh impossible to fail to make the experiment and record the result of his " laboratory work " correctly. By such a plan as I have outlined the student can complete a course of laboratory practice without having gained the slightest conception of the physical phenomena underlying the experiments which he has made, or of the relations of these physical phenomena to the general laws which he has learned in connection with his theoretical work. While such conditions as I have outlined might seem to represent a state of affairs not existing in any of our technical schools, nevertheless, it is to be feared that in many cases too great an approach to them has been made.

If the few ideas which I have here expressed are understood in the spirit in which they are intended, there will be little danger of my being considered a hostile critic of the engineering school and its graduates. So high is my appreciation of the work of our American engineering schools, and so warm is my regard for their graduates, that I wish to guard against that little danger. This I feel I can best and most briefly do by stating that with rare exceptions the possession of an engineering school training is a requisite for entrance to my own office work, and the net result of my experience with engineering graduates shows that the training which they receive, notwithstanding its imperfections, is of great value to them and to those for whom they work.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 3, 1903.

PROPER QUALIFICATIONS OF ELECTRICAL ENGINEERING SCHOOL GRADUATES, FROM THE MANUFACTURER'S STANDPOINT.

BY L. A. OSBORNE.

Any short paper having for its subject the educational needs of a student of engineering must necessarily be limited to the particular requirements to be met. It is therefore proper to state in the beginning that the writer has in mind the requirements of a particular industry and his views are, on that account, influenced by the environment with which he is most familiar.

It is probable that the majority of young men who enter upon a course of engineering in one of our technical schools rarely have expectations of devoting their energies to engineering pure and simple. My experience has shown that the average young engineer rather expects that his preliminary training and education will be of assistance to him in obtaining a foot-hold with the commercial side of industries which are based upon engineering practice. It is not obvious, in seeking for reasons for this attitude, whether our engineering courses are based upon the assumption that the industrial world requires business men with a technical training or whether the supposedly larger emoluments which come to men of affairs rather than to specialists and designers have their effect in diverting the energies of young men after they have departed from the influences which surround them in their academic career, but I believe that the latter form is the determining factor. However that may be, my experience is, that of all the technical graduates who obtain employment with the industry with which I am connected, not more than one in ten is fitted either by temperament or education to take up with success the work of pure engineering.

Temperament undoubtedly has a great deal to do with it, and the tendency of modern industries to demand technical training of men in its commercial departments undoubtedly has the effect of inviting men to take the technical courses, where, if there were not that incentive, they would have devoted themselves to some other line of activity. There is, therefore, graduated every year a large body of men who are added to the engineering profession but who are not properly fitted to deal with engineering questions broadly.

On the other hand, the authors of the courses which these men have followed have generally not pretended or considered any other probability than that the students are to become engineers pure and simple. There has consequently been turned out a body of men who by inclination are not prepared to follow the so-called drudgery of the profession. At the same time they have been given little instruction or special preparation for the lines of work into which they will obviously drift.

I cannot but believe that before the majority of men have completed a four years' course in college they have given some indication to the faculty of their ultimate tendencies. It seems desirable, therefore, either to differentiate between the different classes of men, with the result that each will be better prepared for the work which it will ultimately be called upon to do in the world, or better still to broaden out the courses in certain particulars to the end that the whole body of engineers will enter upon their work with a fuller comprehension of its duties and its opportunities.

I am quite aware that financial and physical limitations will always prevent anything more than an approximation to an ideal. I know from personal contact with many of our educators that they are fully awake to the growing demands of the profession, and that generally the most earnest efforts are being made to meet these ever-increasing requirements. My remarks should therefore be taken in the spirit in which they are given, that is, not as captious criticism of existing methods, but as an endeavor to point out conditions toward which it might be considered desirable to work.

In considering whether the training of the modern engineer is adapted to the demands which will be made upon him later, we should bear in mind certain latter day tendencies which have largely come about through engineering practice.

There was a time in the history of manufacturing when its activities were directed largely by men who had grown up from apprentices in the shops and who were primarily machinists and workmen. The work of modern engineering has resulted in the development of enormous industries requiring skill, intelligence, knowledge and a high order of administrative ability, which were entirely unnecessary in the days of small shops and limited organizations. It has followed that the problems incident to this great industrial development have been more than the limited education and intelligence of the old-time shop superintendent could cope with.

The inventions and discoveries which have revolutionized modern industrial practice have been made by comparatively few men. The activities consequent upon these inventions and discoveries require an army of trained men to supervise and direct them. It is in this army that the average engineer can hope to find an outlet for his best talents. I am not now speaking of the few men who, by temperament and by making the best use of the opportunities offered in the technical schools, will ultimately develop into world-recognized engineers, but of that great body of men trained in engineering. who must look to the more general fields for a proper environment in which to exercise their abilities.

In this short paper it is not my intention to do more than to point out suggestive thoughts, hoping that the discussion, which is always more important than the paper itself, will bring forth the opinions of our members on this question, and will do much to aid us in defining our views upon the subject.

Considering the field of manufacturing, it is my experience that not one engineering graduate in a hundred ever looks to that as holding forth anything attractive as a scene of his future labors. Manufacturing to-day in any industry is a proper field for an engineer. It is unnecessary for me to set forth the countless opportunities which any manufacturing concern, be it great or small, offers for the exercise of engineering judgment.

It is true that our technical schools devote a certain portion of their time to " shop work," and endeavor to give to the engineering student a certain facility in the manipulation of tools, both hand and machine; but it is very seldom that the school makes any serious attempt to take up the larger question of the adaptation of tools to special purposes or give instruction in general in the principles which underlie the tool organization of a shop. Consequently, the student's interest is not stimulated, and the majority of the technical school graduates leave college with but very hazy notions either of the function of tools, the principles of their design, or the machine organization of a shop. In connection with manufacturing, it is also certain that a more thorough knowledge of works organization as applied to the personnel would not only stimulate the interest of the student in this most attractive field, but would be of the greatest importance to his future employers, the industrial concerns throughout the land.

Almost without exception an engineering graduate enters a machine shop in utter ignorance of the principles which should underlie its organization and personnel. It is true that familiarity in these lines comes largely from experience, but it is also true that there are large fundamental facts underlying all successful examples of shop practice and shop organization, the knowledge of which should be of the utmost value to an engineering student.

The man whose work is the supervision of manufacturing processes should also have a competent knowledge of works accounting. Works accounting based upon general accounting practice is a closed book to the average student of engineering. I have been unable to find in the curriculum of any technical school that I have examined any course of study which remotely suggests that this would be desirable knowledge for an engineer. Shop accounting is not a matter for the ordinary expert accountant to deal with. The man who knows the cost of his product—and upon this knowledge success absolutely depends—must apply the fundamental laws of accounting to the particular cases with which he has to deal. There is no more important knowledge required of a works manager than an adequate knowledge of proper accounting methods. In criticism of this it might be said that ordinary accounting and bookkeeping is a subject which any intelligent man might readily master; but my opinion is that it would be much better for our engineering courses to recognize the important relation which this branch of knowledge has to modern engineering work, and the advantage of including it in the curriculum would lie in bringing the importance of the subject prominently to the student's attention.

All engineers, if they expect, as all do, to achieve prominence in their profession, must sooner or later come in contact with labor. There is no more vital subject facing the industrial world to-day than the relations between employers and labor. Every engineer may hope sooner or later to be an employer of labor. To enable the engineering student to understand the economic laws which govern the relations between employers and labor would add enormously to his value in a general way. The engineering student to-day has no insight into these questions except as he may gather his opinions through the newspapers or through such desultory reading as he may choose to do. The result is that he is not brought to an appreciation of the enormous influence which this question must have on our future industrial progress. A course which would bring to the students' attention the history of the relations between capital and labor and the economic laws relating thereto would be suggestive and call to his attention vividly its importance, and arouse in him a realization that this is a question which he some day might be called upon to treat intellignetly.

On the commercial side, all engineers must come in contact with the problems which introduce questions of business practice. The consulting engineer, the engineering salesman, and the designing engineer will, sooner of later, be called upon to enter, either directly or for his employers, and clients, into contractual relations. As it stands to-day the engineering student leaves college with the haziest notions of the principles underlying the law of contracts. Under the circumstances it would seem well if our engineering courses included a short course of law in its relation to contracts.

It may be said that all these things have nothing to do with engineering. This is partly true, but my plea is for engineers with broader horizons. Our technical schools to-day are admirably fitted to turn out men who are well grounded in the fundamentals of engineering. As a rule they are good mathematicians, electricians, chemists, and physicists, and have all the technical groundwork necessary for pursuing the profession, but they are, as a class, woefully lacking in comprehension of many of the subjects which are inseparably connected with the practice of the profession.

I believe that much of the manual training, which now occupies such a large proportion of the " actual hours work " in the courses of most technical schools could be replaced with profit by lectures on subjects related to those which have been mentioned in this paper.

No attempt has been made within this short paper to do more than touch upon what have appealed to the writer as the more important and most noticeable qualities lacking in the mental equipment of the average technical graduate with whom he comes in contact.

DISCUSSION.

PROFESSOR GOLDSBOROUGH:—I am not prepared to admit that the practical men always tell us what we want to know or what they would tell us if they properly appreciated the conditions. The educators of the country have worked hard and have worked well to provide engineering courses that would meet the demands of practical engineering, and they have done it. Because the boys graduate, go out into practical life, and do not *fall down*. That is the measure. *They do not fall down.*

Now, to refer to some of the points made—Mr. Gherardi has taken up the matter of telling us what we should give the telephone engineering students to do. During the last few years I have been working on a course for telephone engineers, which is now published in the catalogue of Purdue University. I have talked to almost every engineer of prominence in the Bell Telephone Company. I have talked with almost every prominent telephone engineer in the independent field; I have talked with the managers of telephone plants, with the presidents of the plants, all along during two years. I have conscientiously gone among them, and the course that we give you *is what they said they wanted*, and nothing else. It is being administered by a practical man; a man who was taken right out of the field; and some of the telephone people are mighty anxious lest he tell those students something that they do not want them to know.

Now, Mr. Gherardi has told us what we should give the men in telephone engineering; that they should have all that electrical engineers now have, and then that they should have a whole lot more besides. And he has not told us where the time for all that is coming from. He has not told us that the young men of this country who are growing up and who are going to be the bone and sinew of the engineering profession, are young men without financial means. They are not the fellows who have been brough up in rich families. They come right out of the backwoods and they have no advantages. But they persevere, they materialize, and they are put in charge of the most important work of these big companies.

Now, as to the best training for a business man. It is not the literary training. The best training, in my judgment, that exists to-day for a business man is the engineering training, because it comes more nearly up to the standard of meeting commercial requirements. We should have in a few years a good course which will teach commercial business engineering. I say " business engineering " for the reason that all of the great work of the future is going to be very largely engineering of one kind or another.

PROFESSOR JACOBY:—It may be of interest to some of the practicing engineers, if they have not followed closely the recent developments in our courses of instruction, that in several of our institutions of learning courses of study are suggested, by which the student may obtain the college course and the engineering, course in six years, by properly electing the work in physics, chemistry, geology and other subjects in such a way that when he gets his degree of A.B. at the end of four years, he will also have completed two years of the engineering course.

Professor A. F. Ganz:—I feel it my duty to say in reply to Mr. Osborne's paper that at the Stevens Institute of Technology during the past year a Department of Business Engineering was inaugurated. Two lectures a week were given by President Humphreys to the seniors on matters of shop accounting, depreciation, statistics, laws of contracts and general business methods. The value of this business training is well recognized at the Stevens Institute and we would like to give more of it but lack the time. Our curriculum is full. Every available hour is taken, and we are doing all that we can do.

In reply to Mr. White's paper and the suggestion that English could be taught to good advantage by requiring reports on laboratory and other work, I would like to say that to make these reports valuable, it is necessary that they should be very carefully corrected by the instructors, both for technical matter and for English, handed back, rewritten by the student. handed in again, and this process continued if necessary until the report is satisfactory in every respect. Unless this is done the work of writing reports is of little value as an exercise in English. We are doing some of this work and hope to do more, but, as I said before, the time is limited.

Another part of our course which brings the students into close contact with practical matters is making inspection trips to power plants and shops where they see how work is done. In addition to numerous short trips to take our senior students every year on a ten days' trip, visiting such places as the Westinghouse and the General Electric Works, various railroad and machine shops and power plants. We come here to Niagara to see the electrical developments. To make these trips of the greatest value it is necessary in my opinion to give lectures before each trip, illustrated with lantern slides, so that for example when a student sees a particular generator in a power house he knows how it is constructed and when he goes down a wheel pit and sees the casing of a turbine he knows how that particular turbine is constructed. I think that this kind of work is very important and together with the work in the laboratories brings the student as close to practice as we can hope to do in a technical school.

Professor Caldwell:—I very greatly appreciate these papers by practical men upon the question of engineering education. For the most part I do not think that the views expressed differ very widely from those held by engineering professors, but they are certainly of great value to us for use with our students as evidence of the needs of the practical man.

The student is very apt to take the view that the details are the all-important thing, and he is inclined to feel that he is being defrauded if he gets a large amount of this more general training, and to be able to point to these papers as evidence of the importance of that class of work is very valuable. I wish, however, to insist that the great difficulty that presents itself to the engineering professor is not what things would be desirable in the course, but what things should be left out of the course in order to get these other desirable things in. I wish that practical engineers who give us such papers as this would give us some views on that subject. It does very little good to tell us that it would be desirable to have all these additional subjects. We already know most of that ourselves. But we do not know what to leave out or what to condense in order to put these subjects in. We do not feel that the practical engineer would be satisfied, to have us leave out anything that we are giving now. To be sure, the subject of manual training has been mentioned, and it has been suggested that that might be cut down. In some institutions that may be so, but in many of the engineering schools at present the manual training in shop work is reduced to what seems to be a minimum, just enough so that the student will have an idea of the use of tools and how they are to be applied in carrying on engineering work.

Mr. Hugo Diemer:—I wish to confine my few remarks to Mr. Osborne's paper only. It has for some years seemed to me that we needed in the shop work in our schools an opportunity for giving the students more in the way of a careful study of sequences of operation, of cuts, of speeds and of the best adaptation of tools to specific work. It seems to me that the introduction of this work is so important that it should be taught, even if it required the laying out of a smaller number of distinct shop exercises. Another point, in my own experience in teaching machine design to mechanical engineers, I have required the students to prepare a complete bill of material of the parts, together with an estimate of weight and cost of material, and a discussion of the details of tools and processes required in turning out the design. With regard to the question of shop accounting and questions having to do with methods of compensating labor, I believe that at the persent day the mechanical engineering departments of several of our leading institutions offer courses in this work, calling them sometimes by the name of "factory organization," sometimes "factory systems," sometimes "shop economics." I have for several years given a term's course in this work, covering five hours per week, which involves considerable collateral reading of current engineering literature by the students. It seems very desirable that students in electrical engineering should also join in such classes since so large a number of the men, according to Mr. Osborne's will be engaged in the manufacturing branch of the electrical field. This fact is too often not realized by the students themselves. We all know that a student, upon graduation, seems very much disappointed if he doesn't get immediately into the field of testing or designing.

Both instructors and students have failed to give due attention to the constructive branch of engineering, and to the principles and methods essential to the most successful execution of the work. It is fortunate that the importance of this branch is emphasized by a man in Mr. Osborne's position, who is both electrical engineer and manufacturer.

I would also advocate in addition to the methods already suggested, that students be given practical experience in the use of representative methods of factory accounting and management in the school shops. I have suggested before the Society for Promotion of Engineering Education in a paper on " Education for Factory Management " that certain of the upper classmen act as foremen and also as accountants and critics of the work, following methods of organization employed in best commercial practice. It may be true that this would be " playing at manufacturing " as it was called by a member commenting on my proposition. It is equally true however, that all of our engineering instruction may be just as fairly called " playing at engineering."

Professor Allen:—I do not feel as I think Professor Goldsborough may, that those papers are unfair or that they attack the engineering professor. If I understand it, these gentlemen were asked to present their views as to what is desirable in an engineering graduate. I do not understand that they were asked or that they attempted to state what should be put into the courses. They state what is desirable, for our consideration, and with the hope and expectation that teachers of engineering will take to heart everything that they say, and so far as possible, bring about the results that to them seem desirable. I should like to state what I think is the problem of the educator with relation to the student. It is impossible that our engineering schools should make a finished engineer. There is not time for that. An engineering college does not have the facilities or the opportunities for doing all that is necessary to make the successful engineer. I have in mind the element of experience. There is left, then, for the college the obligation to provide the student with the proper theory, and to that work the college must be devoted at all hazards. But proper theory cannot be given unless it is united with applications, or what you may call experience, and the college graduate does, as a matter of necessity, if he acquires proper theoretical knowledge, acquire quite a little of experience in that way. I believe, in providing the element of experience; that is, so much as is necessary to give point to theory; and so much as is necessary to put the student graduate in the way of gathering the larger experience which shall make him a complete and valuable engineer.

The manufacturer, I am inclined to believe, is oftentimes disposed to expect too much of the schools. If there are the two things mentioned to be done for the engineer, who shall do each part of the work? The school will do only a part. It cannot do all. The manufacturer with the physical material he uses, expects to receive it in a certain condition, and to put additional work on it before he allows it to depart from his works. I believe that there is another burden on the manufacturer. Part of his outfit is the young engineer. I believe he should put some work on the young engineer.

The matter of accounting has been given as much attention as any other single subject of discussion in the proceedings of our Society for the Promotion of Engineering Education. That an understanding of accounting is valuable and necessary for the successful administration of manufacturing enterprises goes without saying; but where shall the work of training in this direction be done? Are there facilities existing in the school of engineering to take up that work to the best advantage? Should not the manufacturer consider it a part of his duty to take the engineering graduate who is turned over to him and to educate him in matters of that kind, in the regular manufactory, which is a laboratory of accounts, if you please, where the work can be done better than it can in the college of engineering? Without feeling at all positive on that point, my impression is that that is part of the work that the manufacturer should expect to do in producing the engineer whom he wishes to use. The school and the manufacturer should each do the part of the work that it is best capable of doing.

PROFESSOR WALDO:—With Mr. White's permission, I would like to ask him why he retains Latin in his ideal course of study for the engineer?

MR. WHITE:—I think that most of the papers have shown that those of us who have gone into professional life appreciate that the great problem, perhaps, for the educator to solve is how to do ten years' work in four years, and how he can condense into the limited time available a fair general training in " learning how to learn " and some specific knowledge of particular subjects. As to the suggestions made, I would not presume to dictate, or even to suggest specifically, to the educator. I thought it would do no harm, however, to indicate in a general way some subjects which might advantageously have preference over some others, which are also important, but, from our point of view, relatively less important. Latin was not included among those which are considered of primary importance, but it should be in the secondary or perhaps in the tertiary list. It seems to me that students should decide on the amount of time available. If they can take only studies of primary importance, it would perhaps be better to omit entirely those in the secondary and tertiary lists. In such cases it would possibly be best to omit entirely Latin and French and to concentrate the time on some of the more important studies—mathematics, physics, mechanics, chemistry, and fundamental engineering subjects.

PROFESSOR GOLDSBOROUGH:—I want to say that I do not feel that one word of criticism of our teachers has been voiced in any one of the three papers, and if my remarks led any one to think that I have that opinion, I wish now to say pointedly, that such is not the case. *Now, if the practical men will tell us about the course that they put men through after they graduate, what is demanded of them and the order in which it is demanded, and of the attitude that we should teach the student to hold toward his future engineering work*, THEN THEY WILL BE GIVING US SOMETHING THAT WE VERY MUCH WANT TO KNOW. Mr. White's paper gives us a great deal more of this kind of information than any of the others. It is of value in showing teachers the ends for which they must develop their students.

PROFESSOR H. S. CARHART:—I should like to call attention briefly to another phase of engineering education which has not been alluded to directly. It seems to me that there is no necessity for having a differentiation in engineering training in the schools—the differentiation should come in practice, after the man is through with the technical schools. And I have a few times made a suggestion privately which I am going to repeat, and which has met with considerable favor from engineers. It is evident that more time is needed for the training of the engineer. It has been my practice in the little work that I have done in engineering education, to insist upon it that we should teach principles, with enough of the laboratory or the shop, as has been said, to give point to those principles, to connect them with real practical affairs, and not to let the laboratory or the shop encroach upon the valuable time of the student further than this; and I have been greatly gratified when our students have returned, after one or more years' experience outside, to have them say of their own accord that this plan is right, that they can get more experience in practical affairs in six weeks in a large manufacturing establishment than they could get in college in four years. The point I wish to make is this, that instead of trying to make a complete mechanical, civil, electrical, marine, telegraph, telephone, or any other sort of engineer in a training school, we should arrange the course if possible so as to make an *engineer*. (Applause.) Let him apply the adjective after he gets into his practical experience. In other words, it seems to me that it should be the effort to lay a broad foundation in those subjects which the engineer must have to build upon. Now, as you are perfectly well aware, a man graduates as a mechanical engineer and goes out and practices electrical engineering; graduates as a civil engineer, or in the civil engineering course, and goes out and practices electrical engineering: and so on around the whole series. In other words, it is almost never possible to tell during a man's college course in what field he is going to work when he gets through. So that if we could return to the old practice of dividing engineering into two classes, which used to be military and civil engineering, as you are well aware, make engineers of one or the other of those divisions, and have a five year course in which to do it, under the high pressure which seems to be coming into vogue now for all sorts of transmission of energy, possibly we could put into the course what would satisfy everybody.

MR. RUSHMORE:—My remarks are from the standpoint of a man in an engineering office who has had to examine many possibilities to obtain assistance in the performance of such work.

College courses should tend to develop character as well as intellect. Men should have initiative, originality, self-reliance, observation, and above all, accuracy.

The amount of information which a graduate possesses is not of great importance in comparison with an ability to obtain it quickly. Principles should be taught thoroughly. Enough applications come later.

It would express my idea that a college education should not be taken as complete in itself but as the foundation for what comes afterwards.

PROFESSOR WILLIAM KENT:—The criticism made by Mr. Osborne is the same that we have heard for the last 25 years; that is, a criticism of the college graduate because he doesn't know enough. There are two kinds of college graduates: First, the one who is just freshly out of college and who does not know a great deal, and secondly, the man who has taken a post-graduate course in the works " in overalls and grease," as I believe the expression is. I do not think the criticisms Mr. Osborne makes will hold as to the second class of graduates; those who have taken five years' shop experience after graduation and have specialized in telephony, business, engineering accounting or some other branch. I do not believe that these criticisms apply to that kind of graduates. Now, the requirements for an engineer, not an engineering student, but an engineer, which are laid down in Mr. Osborne's paper, are the qualifications of a man not less than 40 years of age, with an experience of at least 15 years after he is graduated.

PRESIDENT SCOTT:—Mr. Osborne will not have attained that age himself for four or five years.

PROFESSOR KENT:—Well, he is asking for more than he has himself then, in these graduates. We must not expect too much from these immature minds, the recent college graduates. What the student gets in the college course is the mental training which prepares him to begin this post-graduate course " in overalls and grease," and the two courses will finally lead to what Mr. Osborne wants.

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THE TYPICAL COLLEGE COURSES DEALING WITH THE PROFESSIONAL AND THEORETICAL PHASES OF ELECTRICAL ENGINEERING.

BY DUGALD C. JACKSON.

At the Chicago meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS held eleven years ago, I presented a paper relating to the subject now under discussion. The proposed subject then apparently created some consternation amongst the members of the committee on papers, who seemed to fear that it was not of sufficient interest to the Society. The old prejudice still held against " college men " in the minds of so-called " practical men," who had grown influential in engineering practice without having had experience of college life and training. Happily, the foundation for this prejudice has ere this been destroyed through the influence of the industrial results achieved by college men. The old prejudice, so far as it now exists, has more particularly drifted into the way of criticism of the engineering schools rather than of their graduates, and the character of the schools and the training they afford are subjects of eager discussion in engineering circles.

This extended interest now manifested in the work of the engineering schools produces a situation which may be of great usefulness to the schools. The character of a college may be that which its alumni determines, and any engineering school may be improved by thoughtful suggestions and broadly considered criticisms emanating from its alumni and others who have its best interests at heart.

Two fundamental propositions must be held clearly in view in all such cirticisms, if they are to be of service to the educational administration of the engineering colleges:

1. That is the business of these colleges to train young men into fertile and exact thinkers guided by common sense, who have a profound knowledge of natural laws and the means for utilizing natural forces for the advantage of man. In other words—it is the business of the engineering colleges to produce, not finished engineers, but young men with *a great capacity for becoming engineers*, the goal being obtained by the graduate only after years of development in the school of life.

2. The problem to be met by the engineering colleges is more particularly a problem in *how to properly train* to the stated purpose. The names attached to the subjects taught are not so important as the results produced by the teaching; namely, the effect produced on the students' powers. This is a teacher's problem: a question of pedagogy, rather than of the engineering profession. It must be met with all the directness and power of the engineer's best efforts, but it cannot be solved as solely relating to the engineering profession. Much error on this point lies in the minds of many who assume the part of critics of the curricula of the engineering schools.

In this connection I may be permitted to point out that proposals set up as apparently new in the presidential address one year ago, by President Steinmetz of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, have for many years been largely included within the ideals of numerous American colleges of engineering. It must be admitted that only few of the engineering schools are living up to their better ideals. This is partially due, on the one hand, to personal or institutional ambitions which father the sensational or spectacluar and thereby inevitably ruin good teaching, and on the other hand, to the meagre support both in encouragement and funds which I have noticed is the lot of the engineering schools attached to many universities. The latter, like the former, is often the result of personal prejudices or ambitions.

Most of the faults which are so trenchantly and indiscriminately charged to engineering colleges by many engineers, should, so far as they are real, be laid to the pedagogical inexperience and faulty ambitions of the authorities of the many colleges; and exception should be made of the few of the first rank in which it is safe to say that the ideals are high and well centered and the administrative organizations hold the ideals continuously in view.

The query here naturally arises: " Of what do these ideals properly consist and how fairly should they be met by the college before its course in electrical engineering may be approved as of first rank? "

Electrical engineering demands industrial engineers—men with an industrial training of the highest type, competent to conceive, organize and direct extended industrial enterprises of broadly varied character. For the highest success, these men must be keen, straightforward thinkers who see things as they are and are not to be misled by fancies; they must have an extended, and even profound knowledge of natural laws (more particularly of those relating to energy which rest on the law of conservation of energy), an extended knowledge of the useful applications of these laws, and an instinctive capacity for reasoning straight from cause to effect. Moreover, they must know men and the affairs of men—which is sociology; and they must be acquainted with business methods and the affairs of the business world. Briefly, to reach his highest influence, each man must combine in one, a man in the physical sciences, a man in sociology and a man of business. All engineers cannot reach this high mark, but the engineering college course should start each of its students toward that degree of attainment which his individual powers will permit.

Michael Faraday (whose conservatism and intellectual clearness are proverbial) said that it requires twenty years to " make a man " in the physical sciences. The engineering school must put each student in the way of becoming, so far as his mental and physical powers warrant, not only a man in the physical sciences, but a man in sociology and a man in business as well; and this must be done within the narrow limits of four years. It is clear that only the foundations of " the man " can be laid in the prescribed time, and the engineering college must, therefore, rigorously hold itself to the fundamentals. The engineering college faculty which is contented to deal out so-called " information courses " on the narrowly empirical side of engineering practice, deals a wrong to its students which they may not recognize at the moment but which will ultimately tell heavily against their success.

The students that enter the engineering schools of the West, and I presume likewise of the East, are from amongst the most vigorous minds of the high schools and the preparatory schools; and yet it must be admitted that they ordinarily possess little power of clear thinking, power of initiative, regard for accuracy, or understanding of continuous and severe intellectual effort, as these important attributes are understood in industrial circles. They are not yet mature in body and are less mature in mind, the latter being, I think, in accord with the natural order of development, but they are commonly well equipped with physical vigor and latent mental strength. Their preparatory schooling has given them a defective acquaintance with the construction of the English language and the spelling of English words, a still more defective acquaintance with French or German or a fairly good grounding in elementary Latin, a smattering of civics and history, a training in the elementary principles of arithmetic, geometry and algebra, from which the factor of accuracy in application has often been omitted, and perhaps an enthusiastic interest in the physical sciences.

This enumeration of the attainments of the students entering the engineering colleges may perhaps be interpreted as reflecting on the seconardy school teachers, but I wish to deny vigorously the validity of any such interpretation. I can truthfully say that, considering all of the conditions, there is no more painstaking and right-wishing body of people than these teachers.

Many of the faults in the preparatory training of our engineering college students are caused by a doubt which is now apparently agitating educational circles on account of the question whether the high schools shall be the " people's colleges " or remain in the station of secondary or " preparatory " schools. This doubt is apparently not yet resolved in the minds of the moulders of educational thought; but the traditional old time secondary school training which produced men who could spell and cipher and who had received a thorough and accurate drill in the details of one language, is certainly to be preferred as a preparation for an engineering college course. In my own estimation, when accompanied with history and a year spent in civics and natural science, it is not only to be preferred as a school course for preparing the student for college but also as a course for those numerous students who cannot go through college.

Taking the students as they come and may be expected to come for the present, the electrical engineering course must include the following branches of learning which are preparatory to the more strictly professional studies:

1. That fuller training in the construction of the English language which is requisite to clear thinking and clear writing, preferably accompanied by an additional language for added strength.

2. The collateral art of expression in drawing.

3. Mathematics through an appropriate amount of calculus including the integration and solution of equations involving derivatives, and instruction in the use of co-planar vectors, and perhaps quaternion quantities, all of which should be taught as applied logic with special emphasis laid on interpreting the meaning of equations.

4. The science of chemistry, soundly taught.

5. The science of physics soundly taught, with particular emphasis laid on the elementary mechanics.

6. Applied mechanics.

Mechanics—the philosophy of matter, force and energy—is the backbone of the electrical engineer's college training.

Instruction in the science branches should be accompanied by well conceived and properly conducted laboratory work, mostly of quantitative character, accompanying and illustrating the class room instruction; and all instruction, whether in natural science, mathematics or languages, should be under the direction of men who are engineers or in full sympathy with the aims and ideals of engineering.

A limited amount of manual training may well accompany these studies; and likewise, if time can be found for it without overburdening the physical powers of the student, a limited amount of proper instruction in surveying (including the use of the compass, transit and level) will always prove a force for quickening his perceptions, and, at the same time, will put him into possession of operations of probable future value.

In a few of our engineering colleges which rigidly demand the best preparatory work from the high schools, and which are, at the same time, best manned in their faculties, not less than two years are required to cover the ground above described, if the work is done in a reasonably satisfactory manner. But the above ground cannot be covered with anything like success in much or any less than three years, in the larger number of engineering schools that are usually accorded high rank.

After covering these branches, it seems to be the tendency in many colleges to fly off into superficial or descriptive courses, relating to engineering practice, during the remaining time of the allotted four years. This is especially apparent in those colleges where the faculties are ambitious to see their graduates take an *immediate* place of considerable responsibility in the world. This is a fault that destroys much of the ultimate advantage which the students may derive from their engineering course. It is a fault, also, which casts just suspicion on engineering education alike in conservative academic circles and in well informed industrial circles.

A resort to mainly descriptive courses of instruction during the latter portion of the students' life in college, largely neutralizes the advantage flowing from the instruction in the fundamentals heretofore described. The students are yet to be taught many things relating to engineering life. They must learn something regarding the forms and formalities relating to the affairs of business life. They must learn the characteristics and uses of materials, their correct application to the building of actual structures, the meaning of kinematics, and the processes of designing and using real machinery. They must also learn to reason regarding the special principles of hydraulics and thermodynamics, the way in which such principles enter into the design, construction and operation of machines, and the manner in which they modify the usefulness of machines and the efficiencies of numerous industrial enterprises. Again, they must learn to reason clearly and rationally in regard to the specific principles relating to applied electricity, including its widely diverse factors, and the way in which these principles enter into every day practice. And they should learn something of the history of the development of engineering and of the lives of its great men, for the stirring of proper ambitions.

The electrical engineering department should be divided into not less than four subdivisions, comprising respectively: Applied electromagnetism, which includes the principles relating to electromagnetic machinery and apparatus; the theory and practice of alternating and variable currents, which includes principles relating to all those numerous phenomena which accompany variable current flow; applied electrochemistry and electrometallurgy; and electrical installations, which includes the applications, in engineering practice of the numerous principles to the design, construction, operation and testing of complete installations and the component parts thereof.

The teaching force of the department should afford a competent expert engineer for the head of each of these subdivisions, and such additional well trained force as may be necessary to carry on adequately class room and laboratory instruction for the particular number of undergraduate and advanced students who attend the college. The head of such a department should spend much of his time in supervising the teaching in class-room and laboratory, which is performed by his various subordinates.

But through all of this professional instruction of the latter part of the course, it is still *principles*, *principles*, *principles*, and rational methods of reasoning which must be taught, if full justice is done the students, until each student becomes a man of open mind, keen observation, analytical thinking, and accurate powers of inference. This instruction should be kept close to the tenets of good practice and the senses of the student should be constantly stimulated by illustrations and problems drawn from practice. The drill in reasoning can undoubtedly be best gained through rational instruction in the useful applications of scientific principles and laws; and no criticism can be justly passed, even by the most conservative educational circles, because the graduate is enabled to earn his living as a result of this training. But the purely descriptive should ordinarily be avoided except in a few cases where it has a specific function in improving the understanding of an appilcation of principles or is adopted as a desirable auxiliary to stimulate the sustained interest of the students and thus add vitality to the teaching. Indeed except for the purposes here defined, the introduction of the purely descriptive into the electrical engineering course, wastes the students' time and injures their training, thus abridging their prospects of utlimate breadth and power.

The typical courses in electrical engineering which are to-day advertised in college catalogues belong to three classes or combinations thereof. Only the third of these may be acknowledged fairly to meet the proper ideals in such a course. It is to be remembered that I speak of professional engineering. No one possesses a fuller sympathy with the ideals of schools for training men for the mechanical trades short of engineering and bordering thereon, but these schools are not considered in my present discussion.

First, are courses in which predominate the old time instruction in physics, with far more to do with the illustration of the beauties of nature than with the great underlying natural laws. The teaching of mathematics, mechanics and like ground work studies is not ordinarily well supervised in colleges that maintain such courses in electrical engineering; because the administrative authorities are out of touch with the industrial world, and mistakenly put the superficial and spectacular in science into the place of that sound instruction only through which an engineering course may be rightly maintained. It is needless to add that the average graduate from courses of this type is ordinarily of less value in engineering than the average graduate from an old time classical course where at least thoroughness is a requirement; and electrical engineering courses of this type are rapidly disappearing through a merging into one of the following types.

Second, are courses in which the ground work studies (English, mathematics, chemistry, physics, mechanics) are perhaps reasonably well taught through the earlier years, but in which the latter part of the course is diverted to the training of inexperienced students for immediate "jobs" where the students may find some responsibility and proportionate pay immediately after graduation. These courses do not teach engineering in the sound sense. They are likely to injure the future of promising students by occupying time in teaching them handicrafts in college which they could better learn in the factory or field, or in teaching empirical methods of practice which change almost before they can be put to useful account by the graduates.

The students in these courses frequently gain the impression that the highest type of engineering practice is no more than an advanced artisanship and that a graduate from the electrical engineering course is the equivalent of a journeyman. The most serious injury flows from this, through the undesirable narrowing of ideals and ambitions. This unfortunate result occurs the more readily because the popular usage of the word engineer makes it denote either an engine driver (a man of purely manual calling) or a man skilled in the principles and professional practice of engineering.

Third, are courses following the ideals which I have herein earlier described. Incompetent students who enter these courses are soon discouraged and drop out. Those whose calling is to artisanship go elsewhere either to a different school or directly to an apprenticeship. Those who complete the course, as a rule, are competent men; but they are not likely to enter immediately into positions of much responsibility, but rather to go into the so-called " cadet " positions or " student " positions of great industrial enterprises for the purpose of gaining that experience in the crafts which may enable them to make the most extended use of their training in principles. Here they gradually " find themselves " and ultimately reach the influence in the industrial world for which their calibre and training fits them. These men, if properly taught, have clean cut ambitions and high ideals as well as the ability to think well and do wisely. Their earnings, and perhaps their usefulness to their employers, may be not so great for a short interval as those of the men who are taught more of empiricism and artisanship and less of rational science during their college course, but the advantage soon flows in a strong current towards the scientifically trained.

The men who are responsible for this third type of electrical engineering courses may reasonably cry to be delivered from judgment upon the success of their work which is based on the average earnings of the graduates during their first year out of college. The medical schools and law schools are judged by the attainments of their graduates reached in a decade or even in a quarter of a century, and this also should be the basis upon which to judge the work of the electrical engineering courses of this third and highest type.

Do not believe for a moment, however, that I would teach all theory and no practice. The earlier parts of this paper prove the contrary. In truth, right theory and the best practice are one, and practice which is out of accord with right theory is mere rule of thumb and can be bettered. The best college course in electrical engineering is the one which so teaches the fundamentals that right theory may be fully grasped, and which constantly illustrates the bearing of theory by examples derived from good practice. The administration of such a course requires thoughtful, clear-headed men, who are acquainted with the principles and right practice of pedagogy as well as trained in the principles and experienced in the practice of engineering.

My discussion of the subject makes it clear that there is a wide variance between the methods of the colleges which support electrical engineering courses. Complete unity is not only impossible but would undoubtedly be undesirable, since scope for individuality is as essential here as in the control of industrial enterprises; but the cause of sound college training for electrical engineers would be advanced by any action which clearly places the true aims of the college courses in electrical engineering before the authorities of all of our colleges which support such courses.

And I may add that many of the greatest weaknesses of electrical engineering courses are due to the fact that the executive heads of colleges or universities do not always understand what engineering truly stands for, and they often have no fair conception of the soundness of training that is required for its practice.

President Scott:—I think it best to have the next paper now, by Mr. Johnston, " Engineering English."

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers. Niagara Falls, N. Y., July 3. 1903.

ENGINEERING ENGLISH.

BY T. J. JOHNSTON.

This paper is a corollary of the discussion at Great Barrington last summer, and refers to only one subject which should be included in the curriculum of an engineering education that is, the English language.

It should be self-evident that the first preparation of the engineer for his profession is to acquire a knowledge of his vernacular, the " first tool of the mind." It has been well said that one who thinks clearly can speak clearly; in fact, we cannot know that the man's thought is clear until he expresses it so that we, having regard to our own limitations, can understand it. That this is true will be borne in upon anyone who is required to consult engineers about what has happened at particular dates. Everyone knows the difficulty of proving precisely the events of the long ago; but here I do not refer to the fallibility of the memory, but to the mere expression of ideas. It is a common thing that no two engineers describing the same phenomenon will give anything like the same description, and this is due not to their want of knowledge of the phenomenon, but to the inaccuracy of their language. That I am not alone in this view is evident from the expressions of competent authorities; I may instance an article of Prof. H. W. Wiley in *Science* for November 28, 1902, page 845, where he says:

" I have often been mortified at the English composition of college and even university graduates. Men who have attained eminence in particular branches of study often seem incapable of expressing their thoughts in any proper way. Their English is inexact, clumsy and inconsequent. Clear expression seems to me to be the legitimate outcome of clear thinking, and the neglect of those early studies which enable one to express himself clearly and forcibly is a fault which can only be remedied by long years of mortification and hard labor."

I also cite the address of Prof. John Perry, to which Mr. Mailloux referred in the Great Barrington discussion.

"Only one subject—Latin—is really educational in our schools. I do not mean that the average boy reads any Latin author after he leaves school, or knows any Latin at all ten years after he leaves school. I do not mean that his Latin helps him even slightly in learning any modern language, for he is always found to be ludicrously ignorant of French or German, even after an elaborate course of instruction in these languages. I do not mean that his Latin helps him in studying English, for he can hardly write a sentence without error. I do not mean that it makes him fond of literature, for of ancient literature or history he never has any knowledge except that Cæsar wrote a book for the third form, and on English literature his mind is a blank. * *

"I ask for a return to simplicity of system. English (the King's English; I exclude Johnsonese) is probably the richest the most complex language, the one most worthy of philologic study; English literature is certainly more valuable than any ancient or modern literature of any one other country, yet admiration for it among learned Englishmen is wonderfully mixed with patronage and even contempt."

"Well-equipped schools of applied science are getting to be numerous, but I am sorry to say that only a few of the men who leave them every year are really likely to become good engineers. The most important reason for this is that the students who enter them come usually from the public schools; they cannot write English; they know nothing of English subjects; they do not care to read anything except the sporting news in the daily papers; they cannot compute; they know nothing of natural science; in fact, they are quite deficient in that kind of general education which every man ought to have."

I do not mean by this criticism that engineers should spend long periods in learning the grammatical and rhetorical construction of the language; but I do mean that English composition should be kept up in engineering schools and that engineers should be drilled in the use of English until they can express with entire accuracy the meanings which they so often commit to formulæ. Pick up any engineering article, and one may rarely read a page without some blunder appearing which spoils the sense either by not saying what the engineer means or by saying what he does not mean.

" Have something to say, and say it," was the Duke of Wellington's theory of style; Huxley's was " to say that which has to be said in such language that you can stand cross-examination on each word." This is the secret of his lucidity.

To show how far from the criteria of style either the " Iron Duke " or Mr. Huxley our engineers are, I quote a few examples of engineering English.

" Generator dissembled."

" More customers, cheaper the cost of production."

" Formerly the slag of steel works was considered purely a dead waste, but some few years ago its valuable fertilizing value was discovered, and now this formerly valueless waste is one of the world's most valued fertilizers."

" Such schemes as M———'s is not a solution."

" A body like you propose."

Of certain generators, it was said they " can not be run in parallel."

" This operation is to be operated at every station."

" In a shaft 8,000 feet deep the cost of *cooling the temperature* would be considerable."

" How much we have had to pay because of the slow speed."

" Details as to *how small* turbines could be manufactured."

" Encourages attack upon the doctrine of the right * * * to control their business * * * ."

" This discharge took place perfectly regular."

" There is no reversing plugs."

" For which the unenviable distinction of being the worst in the world is often claimed for it."

" To this was added two * * * generators."

" Gas engine would develop along the same lines as the steam engine had done."

" The low height of the turbine permitted a reduction of the height of the engine room."

" The correctness of my conclusions have been amply demonstrated."

" This can be done equally as well with the motor at no load as at full load."

" Four motors * * * will perform a faster schedule."

" An almost infinitestimable amount."

" The last two thirds." (of a commutator brush).

" The matter of convenience * * is shown in every detail."

" Brackets cast solidly with frame."

" The rings * * * are circular in shape."

" One and the same motor."

" The car is well lit."

" Not only securing pole (pole-piece) but also of drawing same down to the tightest of magnetic contacts."

" The cost of superimposing a second floor on the present system would cost as much as the original cost of building the present system."

" The company find it impossible to buy only at retail prices."

" Which renders great economy and rapid construction."

" The three top voltages were the * * * ones * * * used."

" Trains can run at fast speed."

" The hollow of both electrodes communicate with the open air, and when in contact form an air-tight joint."

" Their errors " (of electrical measuring instruments), " were determined by taking them to the works of the Weston Co."

" Continued to do good work when pronounced as ruined."

" We do not think present conditions demand."

" A fewer number will perform a given amount of work four times as long as any other cell of equal size."

" There is no question but that."

" It would have been better to have had."

" Why does a cell constant change when the density of the solutions change? "

" The lapse of time which are here chiefly in question."

" Not yet fully decisive."

" The correct solution for the problem of cause has been discovered."

These (about five per cent. of those I have seen) have been gleaned since the Great Barrington discussion, from reports of engineers, descriptions of operations furnished to engineering periodicals by engineers in charge, and " woe is me," from letters to the techincal press written by professors of applied physics in universities. I regret to say that some of the most glaring solecisms are from the last named source.

Wendell Phillips once said that there are only thirty-seven jokes in all languages, but Mr. Phillips died before electrical engineers had written much.

It is only necessary to refer briefly to the inaccurate use of terms common in the profession, and particularly to double meanings applied to well-known words which should be terms of precision. " Static transformer," when stationary transformer is meant; the " capacity " of a system, when the maximum output is meant; the " field " of a generator, when the field-magnet is meant, are common examples of the appropriation of a well-known term to a new use, generally inaccurate. " The time would fail me " to do more than shake hands with our old enemies. " Equally as well," " the two highest," " one and the same," *et id omne genus.*

I see many mining engineers in the course of the year. Respectable vagrants as they are, their correct and often elegant diction is a surprise and a pleasure, and somewhat of a reproach to our own members; though a mining engineer, to be sure, would have but a dry practice if he could not furnish the materials for a good prospectus.

This is no protest against the study of languages other than English. *Per contra*, just as no man can be a sound mathematician who confines his study to algebra or trigonometry, so no man can learn English thoroughly without some comprehension of its sources in other languages. The true meaning of a word can only be learned by learning its root, and from that its trunks and branches are easily understood.

Let no man say " I am too old to take up such studies; they were neglected in my youth, and I am as I am." Caleb Cushing, Attorney General of the United States, statesman, diplomat, and jurist, learned in literature and science, began the study of French when he was seventy years of age. The subsequent proceedings are not generally referred to; but having heard Mr. Cushing's French, I may add that although public safety prohibited his pronunciation, his knowledge of the shades of meaning of the spoken language would have shamed many English-speaking persons long resident in France.

Most of the errors in Engineering English are due to want of attention; few engineers revise the language of their reports and articles as they do the tables and formulæ upon which the text is based; fewer still, even in important investigations, think it worth while to have the text read by another to detect errors.

I may quote from President Woodrow Wilson's inaugural his unanswerable plea for a liberal education, as a special plea for adequate instruction in English, either as a preparation for, or better still, for both that and a part of an engineering course.

" No doubt the old, purely literary training made too much of the development of mere taste, mere delicacy of perception, but our modern training makes too little. We pity the young child who, ere its physical life has come to maturity, is put to some task which will dwarf and narrow it into a mere mechanic tool. We know that it needs first its free years in the sunlight and fresh air, its irresponsible youth. And yet we do not hesitate to deny to the young mind its irresponsible years of mere development in the free air of general studies."

" What we seek in education is a full liberation of the faculties, and the man who has not some surplus of thought and energy to expend outside the narrow circle of his own task and interest is a dwarfed, uneducated man. We judge the range and excellence of every man's abilities by their play outside the task by which he earns his livelihood. Does he merely work, or does he also look abroad and plan? Does he, at least, enlarge the thing he handles? No task, rightly done, is truly private. It is part of the world's work."

" A merely literary education, got out of books and old literature, is a poor thing enough if the teacher stick at grammatical and syntactical drill."

" It is not the education that concentrates that is to be dreaded but the education that narrows—that is narrow from the first."

Do we not all assume too readily that because we speak, or think we speak, English, our expression of the thought in our minds is impeccable? Is not our vocabulary too strictly professional? Does it not cramp the intelligence and impair perception? Ought we not to " break their bonds asunder," and learn thoroughly to use the master-tool—English?

NOTE BY THE AUTHOR.

At the instance of Professor Kent, of Syracuse, I add to the " Chamber of Horrors " the expression " the data is limited," as an example of mistaking a plural for a collective.

T. J. J.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers. Niagara Falls N. Y. July 3, 1903.

TRAINING AN ARTIST IN THE FORCES OF NATURE.

BY E. H. MULLIN.

If we go back in the history of our language, to the first known use of the word " education," we find that in 1540 it had as its meaning " the process of nourishing or rearing a child or young person." It will be noticed that in this case, as in so many others, a term which may now be regarded as meaning something abstract and psychological is derived by metaphorical extension from an earlier concrete and physical concept. Yet if the word " education " has gained in breadth since its first use four and a half centuries ago, it has also lost much in depth—at least as commonly used. The essence of the word " nourishing " is assimilation; it conveys the idea of the food which is most easily converted into life-giving blood, and thence, with hardly a pause, into nerves, bones and muscles, to become an inseparable part of our bodies. For one reason or another, we seem to have passed beyond the stage of a simple educational diet which can be thoroughly assimilated; we present either the jaded palates of a worn-out race, or the capricious appetites of spoiled children. Instead of the educational roast and boiled joints of our forefathers, we toy with highly seasoned *entrées* which blunt our appetites for the time being, but do not give us the strength for long fasts, the energy for great work, or the physical repose necessary for deep thought.

We shall find, if we keep the idea of assimilation as the primary attribute of all education, that the physical and mental analogies are reasonably close and hardly, if at all, misleading. Mental indigestion from over-stuffing, no less than physical indigestion, produces cloudiness of the brain. Mental dyspepsia may follow a diet of too large a variety of elective courses, just as physical dyspepsia may follow over-indulgence in highly spiced but non-assimilative foods. In both cases time is an indispensable factor to assimilation; plain food will be most enduring in results; maximum efficiency will be found in maximum assimilation and minimum waste. Fixed habits are perhaps the most valuable gift we can receive, whether from home rearing, from college training, or from that first part of our lives passed in the world of men. Yet granted that we have taken a firm hold of essentials, we may pursue cognate non-essentials as an enlightening means of recreation. Every author has his historical background; every science has its borderland; every art has its path of development. Knowledge is the result of profound study; culture is the reward of diligent exploration. With knowledge alone we are as flatlanders, realizing our neighbors only when we touch them, by the aid of culture we can rise above our surroundings, and, by viewing the relation of our neighbors to each other, form a juster estimate of our relation to them.

For, in our realization of our true relationship, to the whole of the outer world lies the benefit of our education. The pure specialist, without sympathy and without comprehension is simply a machine tool in the hands of a higher order of intelligence. When Mr. Carnegie claimed for himself only the power of acting as a magnet for much abler men, he either meant much more than he said, or said much more than he meant. To utilize ability, to turn it into its proper channels, to mark the time and place when and where one kind of specialized mind should begin and where it should stop to allow the next specialized mind to take up the running, is the function of true greatness. The general in command of armies, the statesman responsible for a party, the captain of industry with sucecss or failure hanging upon his decision, asks no more than that the subordinate whom he chooses can convert his ideas into action. " Be bold, be bold, be not too bold," said the ancient sage. "Specialize, specialize, but don't specialize too much," says his modern analogue.

Capital, modern economists are agreed, is the crystallized savings which can be lent out to reproduce itself in useful work. It is, in fact, stored energy. In its baldest form, capital represents the wheat saved from last year's crop to enable the laborer to garner next year's crop without dying of starvation while next year's crop is growing. In its broadest sense, education is not capital but tools. It is not the knowledge of facts which makes a man educated but the possession of method. To teach a man to learn how to learn is the true function of education, and to stuff his mind with facts beyond this point is merely to encumber him in pursuing his means of livelihood. It is true that the method of education adopted may, and perhaps should, bear some relation to ultimate ends. The future classical scholar will save himself much annoyance by a diligent study of Greek irregular verbs. The future mechanical or electrical engineer will enjoy an ease, not otherwise procurable, by a thorough mastery of elementary mathematics. But, still, education is not so much intended for the elucidation of old problems as for the tackling of those that are new. And, as a knowledge of facts without the power of ratiocination is worthless for new ventures, and as every problem which meets us in life is a new venture, therefore, method by itself is everything, and facts by themselves are nothing.

The faults of technical education of the present day are that they tend to reproduce a microcosm of real life. Everyone has heard of, or has seen, a typical specimen of the " tank drama," in which there is real water, real horses, a real fire engine, or what not, to heighten the verisimilitude. The technical colleges which attempt to make a blacksmith or a mechanic out of a student, fail, just as the " tank dramas " do, by endeavoring to make their courses a miniature copy of future work instead of making them typical of crises and illustrative of principles. Let us glance for a moment at the two great professions where education, as commonly understood, utterly fails to supply a man with the power of commanding success. It will be acknowledged that painting is an art which requires initiation and instruction. Yet, without genius, without inspiration, even the most skilful painters have been unable to rise about the ranks of mediocrity. The Italians call Andrea del Sarto " the faultless painter." But, as Symonds says, he lacked inspiration, depth of emotion, energy of thought, and cannot therefore take rank among the great Renaissance painters. Or take again the two typical cases of the Archduke Charles and Major General Halleck, for both of whom it may be claimed they were bright and shining examples of profound technical education in the military art. The genius of Napoleon, not a particularly distinguished student, overthrew with ease the strategy of the Archduke Charles, while all that Halleck's technical knowledge seemed to be able to do for him was to point out every possibility of defeat without inspiring him to a single means of victory. More recently we have seen Sir John French, the only really successful cavalry general of the South African war, overthrow in the field the reputation which the pedants of Aldershot gave him of not being able to handle a cavalry brigade.

We may gather from these examples, and from others which will occur to the minds of every one, that all that technical education can do is to give each man his chance of success or failure. Genius may be able to dispense altogether with technical education; inherent stupidity will ultimately sink to its true level, in spite of the most careful collegiate training. In considering educational matters, therefore, we are concerned not with geniuses or with muddle-heads, but with average men. How the average man may be trained for a profession for which he feels within himself some aptitude is the question which it behooves us to answer. And the answer which we should give is to teach methods, to instill principles, to lay deep and sure the foundation of elementary knowledge, and trust the future to take care of itself. We have, therefore, two co-related branches of education to consider—education as an art and education as a science.

Education as an art involves perfect familiarity with a larger or smaller number of facts, according to the purpose to which these are to be devoted. In this age of universal reading and writing we are apt somewhat too hastily to assume that a categorical knowledge of the alphabet and the arithmetical tables is necessary to success in life. Those who have lived in countries where a considerable portion of the population is wholly illiterate must have often been struck by hearing men who could not read use language all but grammatically correct, or by observing intricate accounts made up by mental arithmetic without the aid of either multiplication or division. It must also be remembered that in the Dark Ages kings and bards were usually illiterate, though they were none the less the rulers and inspirers of their times. Education as an art, therefore, must be separated from personality on the one hand and from mere pedantry on the other. We may compare education as an art to a knowledge of the names and functions of the pieces on a chessboard divorced from any knowledge of the game of chess itself. If we can then imagine a series of chessboards, each having more pieces than the one preceding it, and each set of pieces having more complex moves than the set preceding it, we shall have a fair analogy of the gamut of education as an art, from simple elementary education to the highest classical or mathematical standard. Throughout this series there are things to be known by name —what may be called primary concepts—and these mere names have to be clothed with ideas or attributes or functions, by means of which we may see how far we can utilize them. In other words, in education as an art we have to exercise the faculty of memory, and this memory must be clear and accurate if our minds are always to have their tools at hand ready for instant use. But this in turn implies familiarity and familiarity implies constant practice for a longer or shorter time. Here again our average education for the average man comes in. If we have in mind only the first 25 per cent. of our pupils—the geniuses and the hard-reading men—we shall pass along to the next stage before our 50 per cent. of average men have had time to become perfectly familiar with the facts and their connotations which are being studied. If, on the other hand, we attempt to wait for the last 25 per cent. of our pupils—the incorrigibly idle and muddle-heads—we shall waste the time of our 50 per cent. of average men. In every stage of education as an art we have therefore two things to consider, namely, the accumulation of a sufficient number of names and their connotations to give us an ample nomenclature or set of tools, and also enough familiarity with this nomenclature or set of tools to enable us instinctively to select the right tool and to use it efficiently.

Let us now pass to education as a science. A man might know the dictionary from end to end, and yet not be able to use more than one thousand words of it for any particular purpose. Having obtained our tools through education as an art, the problem in education as a science is not to use them as we have been taught but to apply them to new problems. To go back to our former illustration we must be able to play the game of chess after having learned the names of the pieces and their functions. It took the world 2,000 years to find out that deductive logic could state nothing new beyond what was contained in the premises. Science, we are told, is organized and classified knowledge, and the first thing a truly educated man will do with a new fact is to place it under its proper classification—that is, he will refer it to the principle which governs facts of a similar kind. Not only, therefore, is memory needed here but imagination. A man's whole education goes for nothing if in dealing with a new fact he cannot see resemblances in it to other facts where none outwardly exist, or cannot see profound differences between a new fact and an old one where the outward resemblance is strong. And the highest function of education as a science is to make a man of average ability see resemblances and differences in cases where he would otherwise be blind. Indeed, genius itself, as we see it in the great inventors, is usually nothing more than the power of classifying a fact under its proper generalization and then re-stating it in terms of some other fact classed under the same head.

Rising stage by stage, therefore, according to the future for which our educational requirements are to fit us is our elementary knowledge plus perfect familiarity in dealing with and handling it. Better, far better, that we should know little but be on terms of perfect familiarity with that little, than we should know much and have to grope for what should spring to our minds as quick as thought itself. The time spent, the labor involved, in obtaining an absolute mastery over our primary concepts or elementary knowledge marks the difference in our future work between having strange tools to handle and having tools which so fit into our hands as to become an inseparable part of ourselves.

Let us turn now to the education of an engineer. The definition of an engineer, according to Telford, is one who applies the forces of nature to the service of man. Mr. Mansergh, recently President of the Institution of Civil Engineers, quoted with approval an American definition of an engineer as " a man who could do for one dollar what any fool could do for two dollars." Perhaps the best definition will lie somewhere between these extremes. If a man does not know how to apply at least one form of the forces of nature to the service of man he is not an engineer; and if he cannot do this more economically than an outsider no capitalist with common sense will employ him. An engineer differs from a physician or a lawyer in that patients die and cases are lost without damaging the reputation of a member of either of these professions, while, on the other hand, an engineer's work must speak for itself. The motto over Sir Christopher Wren's tomb in St. Paul's might be adopted as that of the engineering profession as a whole, " *Si monumentum requiris circumspice.*" Posterity camps on the trail of the engineer, and its conclusions, like the judgments of the Lord, are true and righteous altogether. Whether it be the aqueduct of Rome or the Brooklyn Bridge, whether it be a generator at Niagara Falls or the switchboard of a New York power station, it will either form a model from which other generations of engineers will expand into new conceptions to meet new needs, or it will become a beacon post to point out the way which is to be avoided. Verily, it is no light thing to train up an artist in the forces of Nature.

Let us begin with the prime essential. Without reverence for great works and for the great men by whose agency they were brought forth, there will be no great engineers. Granted that, a sound knowledge of one's native tongue is the best substructure. The great engineers who have been deprived of this aid, have borne eloquent testimony by their efforts at self-improvement in later life to what they considered would have been its usefulness at an earlier period in their careers. An elementary knowledge of Latin is most indispensable to the clarification and consolidation of the knowledge of nearly every European tongue. Next to these my vote would go to a good working knowledge of French because besides its obvious advantage as a language to be spoken, it imparts lucidity and precision to writing—a thing, by the way, which mathematics often fails to do. Early practice in mechanical drawing should also be given to every boy who feels within himself the stirrings to become an engineer, because familiarity with the pencil is easily acquired early in life, but is often one of the greatest stumbling blocks when taken up too late.

Then as to mathematics. As the profession of an engineer always involves constant dealing with quantities and values, he ought to know mathematics as he knows the currency of his native country. In other words, he ought to be able to make change with ease, quickness and accuracy—not as if one were in a foreign country in a constant state of painful reckoning. A thorough knowledge of ordinary mathematics is here prescribed, not any vain ascents with crippled wings into the empyrean. What is meant by " ordinary mathematics " may perhaps be more clearly indicated by a remark and an anecdote. One may make accurate change without any knowledge of the science of numbers. Lord Salisbury, when President of the British Association, told the story of the old Oxford Professor who said to him fiercely, " What I like about quartenions, sir, is that they cannot be used for any base utilitarian purpose."

This makes our substructure complete. The first part of our superstructure should consist in learning the principles of the applied sciences. These should be studied in books, assisted by oral teaching, and enforced and re-enforced by the practice of dozens or hundreds of examples. If one wants to know how each principle should be learned, he should watch a great singing teacher train a pupil. A false note in a scale demands a hundred perfect repetitions. A false note in an *aria* means back to the scale for a hundred more repetitions before attacking the *aria* a second time. Why should the future artist in Nature be less carefully prepared for his work? Is that work likely to be less important? Or is it merely because his future audience is less likely to detect a false note?

With this, the education, of our engineer ends or rather begins. He may be fifteen, sixteen or any age. He may have studied in school, or in college, or at home. He is, however, a trained engineering soul, according to the measure of his talents. He is able to learn the art of engineering, or any other art, for which he has an aptitude, in months, where another man of equal ability might take years and not know it half so thoroughly. All he needs to ensure his success in life is to find a master who can utilize his powers.

President Scott:—One of the speakers said that an engineer ought not to be judged until he had been in practical experience for, say, 25 years. If you set that standard, then, we cannot begin to receive a verdict on the modern electrical engineer for 10 or 15 years to come. The modern electrical engineer is a new engineer. He has a new kind of work. The census shows that electrical work as represented by the capital invested increases something like 20 per cent. a year. Men are needed rapidly and the followers of engineering, and particularly of electrical engineering, have as their principal function in the world, increasing the efficiency and the effectiveness of modern life; so it behooves these two societies which are represented here to-day to unite and to expend every effort for the more thorough production of efficient engineers.

On motion of President Woodward the Convention adjourned *sine die*.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, September 25, 1903.

The 179th Meeting was held this date at the New York Academy of Medicine, 17 West Forty-third Street.

President Charles F. Scott, of Pittsburg, called the meeting to order at 8.20 o'clock and said:

During the past year the fundamental characteristic of our work has been extension and expansion, both in our various activities and also territorially. I believe that never before have the members of the INSTITUTE throughout the country felt the same direct interest in the INSTITUTE, and the same personal contact with its affairs that they do at this time. I believe that the various movements in several lines, particularly in the organization of local branches, during the past year, are but the beginnings of a great future for the INSTITUTE. We have been laying a foundation upon which a magnificent structure may be erected. It is, therefore, particularly appropriate that our leader, the President of the INSTITUTE, should at this time be a man who represents the Western part of the country. I believe this sentiment is one which has been growing among our members and that the part of the country from which the President as well as our other officers are selected, is becoming a more and more important element in the choosing of our officers.

It is, therefore, with great pleasure that I now turn over the Presidency of the INSTITUTE to my successor, and introduce to you the man whom you have chosen for your President, Mr. Bion J. Arnold, of Chicago.

PRESIDENT'S ADDRESS.

Members of the Institute:

Our new Constitution does not call for a formal address from the incoming President at the time of his inauguration, as this duty is required of him at the annual convention. My worthy predecessor, however, outlined his course on taking office and followed it so well and with such signal benefit to the INSTITUTE, that his action prompts me to, briefly, point out the lines which I believe we should follow during the coming year.

The remarkable development and growth of our body during the past two years has introduced many new elements which must stand the test of time and possibly be tried in a period of financial depression. Our energies, therefore, should be directed toward carrying forward the work, so well started by my predecessors, upon conservative lines which will insure its permanency and result in the greatest good to the INSTITUTE.

First.—For obvious reasons our recent great rate of increase of membership cannot continue indefinitely, and our expenditures should therefore be gauged to meet this condition.

Second.—Our local branches should, if possible, be made to last after the enthusiasm, born of novelty, has worn off, which implies encouragement from headquarters and sustained effort on the part of the local members.

Third.—The work of our special committees in connection with electrical engineering standardization and the collection of technical data should be encouraged and additional committees appointed to extend the work in other promising directions.

Fourth.—We should allow the authors of our papers more time for presenting them, and our members more time for their discussion, even, if to accomplish this, we are compelled to have fewer papers.

Fifth.—Contributions making provision for our interest in the land for the engineering building should be placed in a separate fund which should be set apart from all other INSTITUTE funds and to which should be credited all funds for building purposes now on hand, and subsequently received for such purposes from donations or from the sale of bonds or other securities.

Sixth.—Our library fund should also be carried as a distinct fund and all donations and appropriations for library purposes credited to it, all expenditures for library purposes to be debited to this fund.

Seventh.—On account of the International Electrical Congress to be held at St. Louis in 1904, we shall be called upon not only to contribute to the scientific value of this congress, but to receive and entertain many distinguished guests and members from foreign countries. Our plans should, therefore, be so well and broadly laid and executed that our guests shall return home not only fully repaid for their visit among us, but shall also feel that the splendid hospitality which was shown us as a body on our trip abroad in 1900, and to our individual members before and since, has been fully appreciated.

Eighth.—Our relationship with the other large engineering societies of this country have, during the past year, become more intimate, and we are now about to join with them in the ownership and management of a union engineering building which shall meet the needs of all. The general preliminaries have been perfected and the work of the coming year will consist in the crystallization of the plans and the origination of definite means and methods for raising funds and for promoting the material progress of the work.

I trust we may be able to carry to a successful conclusion the work so splendidly initiated by my predecessor, Mr. Scott, and his able lieutenants, and in such a manner as not only to retain but to heighten the respect and good will of those who may coöperate with us; and by the adoption of rational methods and the exercise of good business judgment, in carrying out the work, insure that the generous gift of Mr. Carnegie to the engineering profession shall in its material culmination attain the ideal that he hoped for.

I wish to express my appreciation of the confidence you have shown in me by placing me at the head of this INSTITUTE, the youngest, yet one of the most progressive of the several great engineering bodies of this country. I sincerely thank you and I feel that you will accord to me such harmony of action and support that the coming year may be of the greatest benefit to our membership and add in some slight degree to the prestige of the engineering profession at large.

A paper presented at the 179th Meeting of the American Institute of Electrical Engineers, New York, Sept. 25, 1903.

AN EFFICIENT HIGH-PRESSURE WATER-POWER TRANSMISSION PLANT.

BY GEORGE J. HENRY, JR., AND JOSEPH N. LE CONTE.

An interesting hydraulic electric power transmission plant has recently been started in Southern California by the Edison Electric Co., of Los Angeles. The water pressure of head employed is equal to 1960 feet vertical fall, which is obtained in something over 8000 ft. length of pipe-line. This gives an effective pressure—after making allowances for friction loss—of considerably over 1900 ft. head, or 825 lbs. per sq. in., equal to 55 atmospheres.

The station is located about ten miles from Redlands, in Southern California, and is used on an extensive system, including a number of other power stations, for transmitting power to Los Angeles and largely for irrigation pumping in the San Gabriel Valley—celebrated for its oranges and other tropical fruits.

The generators are of 750 k.w. normal capacity each, running at 430 revs. per min., and the water wheels are of the tangential type and mounted on the same shaft as the rotor. This shaft is 9″ in diam. where the wheels are pressed on, and is of forged steel, carried in three generator ring-oiling bearings—the water wheel being located in what would ordinarily be the pulley compartment of the generator. The box bed-plate of the generator is enlarged to surround the water-wheel pit, and has an opening of 3 ft. 4 in. × 10 ft, 2 in., and is planed and fitted along water-tight joints with the water-wheel housings. These are thoroughly stiffened with internal ribs and provided with centrifugal discs and pockets for preventing leakage of water from the interior of the wheel compartment to the outside, entirely without friction.

Each generator is fitted with a single wheel or runner, which, on account of the enormously high peripheral speed of 170 ft. per second, is made of a special rolled-steel plate, thoroughly annealed and turned to eliminate all shrinkage strains. The high speed involved is entirely beyond the limits of safe practice for cast iron, and large cast steel discs contain such dangerous shrinkage strains, in spite of the ordinary annealing process, that it becomes dangerous to employ them under such high water pressures. In addition to the centrifugal strains in the rim of a wheel of this character, we have the strains due to water impact on the buckets. This amounts to about 22,000 on the front bolt of each of the buckets.

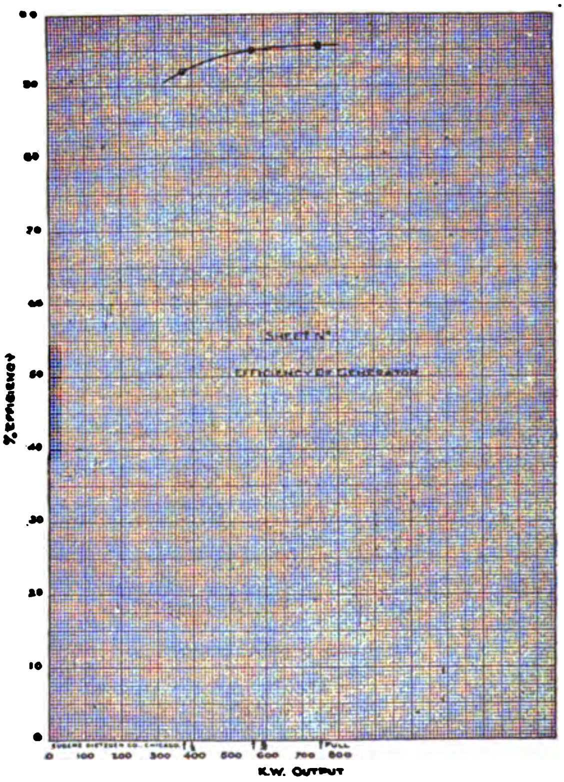

Fig. 1

The buckets are of soft open-hearth steel castings, thoroughly annealed and machine ground, and polished on the inside to give perfectly smooth and true curved surfaces for the water to flow over. The front edge and centre knife of each bucket is dressed to a perfectly true cutting edge and carefully centred on the wheel rim. The buckets are cast with heavy internal projecting lugs, which are milled out and driven over the wheel centre rim.

The wheel hubs consist of heavy semi-steel castings, to which the steel disc is securely bolted by turned nickel-steel bolts driven in reamed holes. This disc is turned perfectly true all over, and carefully adjusted to a running balance at 430 revs. per min. In actual operation about 200 buckets come under the action of the high pressure water jet every second.

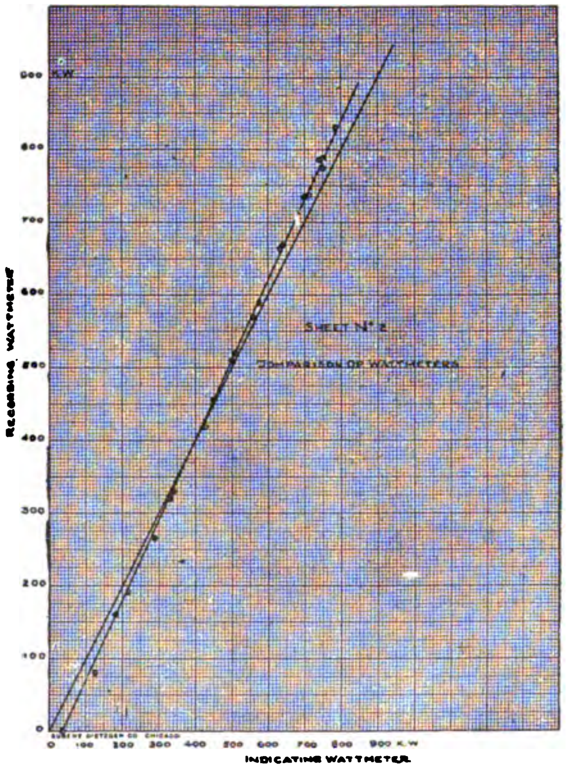

Fig 2.

The wheels were built for a maximum overload capacity of 50 per cent., and for continuous service of 24 hours a day and 365 days in the year, and no trouble is experienced from the cutting of the buckets and nozzles by the high pressure water, as after five months' operation the wear is almost imperceptible. The water is usually clear, except for an occasional storm, during which considerable sand and gravel may be washed down into the reservoir at the top of the pipe-line. The most severe storm known for many years washed considerable sand down the pipe-line just after the wheels were installed and started up, but the steel buckets show no appreciable wear as the result of such severe treatment.

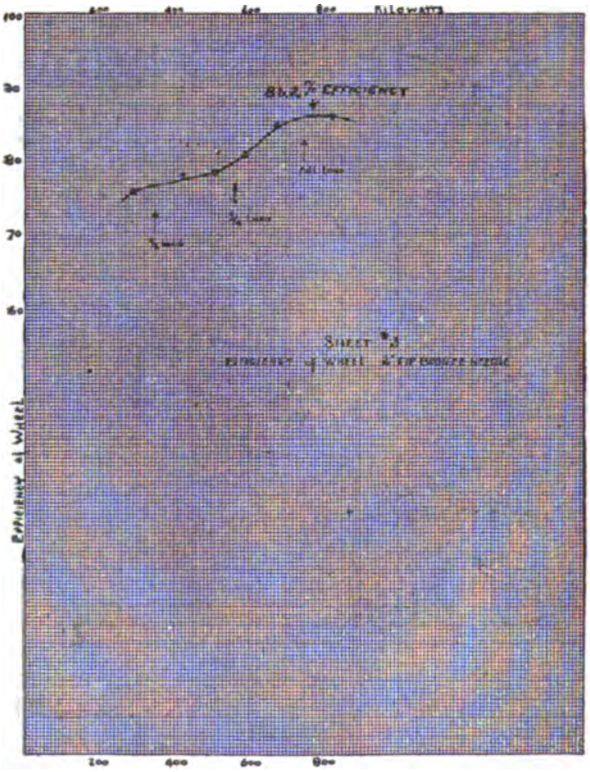

Fig. 3.

The main pipe-line consists of:

2485 linear feet of 26″ inside diameter sheet-steel riveted pipe, varying in thickness from 14 B.W.G. to 6 B.W.G.

Below this is 2990 linear feet of 24″ inside diameter sheet-steel riveted pipe, made of gaugus running from No. 6 B.W.G. to $\frac{9}{16}$ of an inch.

Up to this point the design of the pipe-line is largely in accordance with well-known practice, but from this point down the pipe consists of:

360 ft. of 24" outside diameter ½" thick, lap-welded steel pipe
260 " " 24" " " 9/16" " " " "
414 " " 24" " " ⅝" " " " "
956 " " 24" " " ¾" " " " "

And below this:

620 ft. of 24" outside diameter, ¾" thick, lap-welded steel pipe.

The 20 ft. lengths of the last 620 ft. are jointed together with solid steel flanges welded on the ends of the pipe sections, all of the other 24" lap-welded pipe being put together with " bump " joints.

At the lower end of this flanged pipe the line branches into two forks, each of which is 18" outside diameter of ⅝" thickness and 45 ft. in length. From each of these terminals the pipe again branches into two lines, each being 14" outside diameter and ½" thick, lap-welded—each branch being 40 ft. in length and terminating just outside of the power house wall in the cast-steel taper pipe immediately above the gates of the water wheels. The branch from the 24" to the 18" and the two branches from the 18" lines to the 14" are made of heavy annealed-steel castings. The main pipe-line, just before the cast steel Y to the 18" branches, is supplied with a heavy pressure, outside screw and yoke, 24" gate valve, and each of the 18" branch lines are supplied with similar high-pressure cast-steel valves so that the water supply to each of the water wheels, or groups of water wheels, may be entirely shut off without emptying the long pipe.

The main pipe is protected from accidental water-hammer by several air-chambers of large capacity with the necessary equipment of charging tubes, to recharge the chambers as the air is carried away in solution. The 14" branch pipes supplying each unit, feed through a cast-steel taper pipe and through a 10" single disc, cast-steel body gate valve of outside screw and yoke construction, with Tobin bronze valve stem and with roller bearings for taking up the thrust on the gate-nut in each direction. All of the gate valves are provided with by-passes to reduce the strain when the gates are opened or closed.

The nozzle is one of the most interesting features of the installation. It consists of a combination needle and deflecting nozzle. The deflecting joint is arranged for giving the best possible regulation without water-hammer or shock in the pipe-line, and water economy is secured by the needle nozzle of the Clemmons type. The deflecting nozzle is fitted with a high pressure ball joint pivoting on nickel steel trunnions, working in oil packed gun-metal bushings and with leather packed ball joint. By the motion of the deflecting nozzle the stream may be easily thrown on or off of the buckets by hand, or automatically by the hydraulic governor. It will be readily appreciated that this

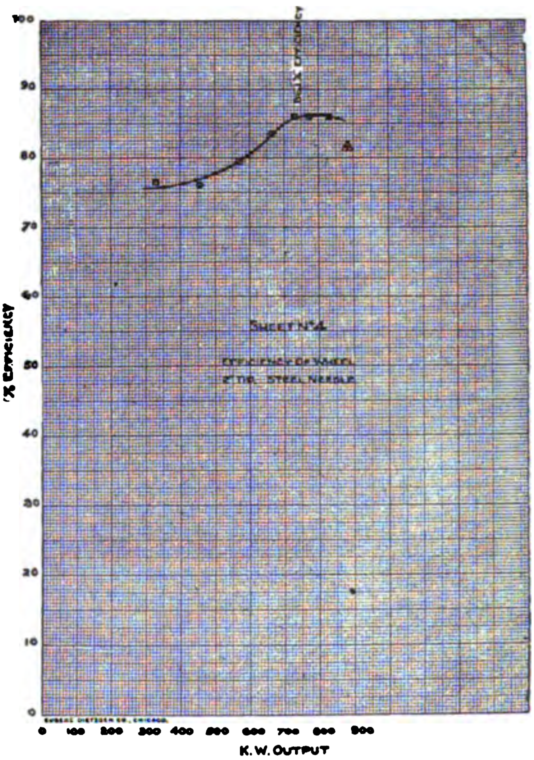

FIG. 4.

enables the operator to vary the power output from the wheel from zero to maximum instantaneously and with very small effort, without in any way varying the velocity of water in the main pipe. Absolutely no shock is thus occasioned in the pipeline by the action of the governor due to fluctuations of the load.

The most accurate regulation is further obtainable owing to the very small amount of inertia in the moving parts—the deflecting nozzle joint weighing but a few hundred lbs. and being accurately counterbalanced—whereas in turbine installations the unbalanced gates and the inertia of the moving water column seriously interfere with satisfactory regulation. The governor is in no way connected with the operation of the needle, which is for the purpose of regulating the flow of water through the nozzle at different hours of the day, and is accomplished through suitable geared connections to a floor stand located above the power house floor. The method of operation is as follows:

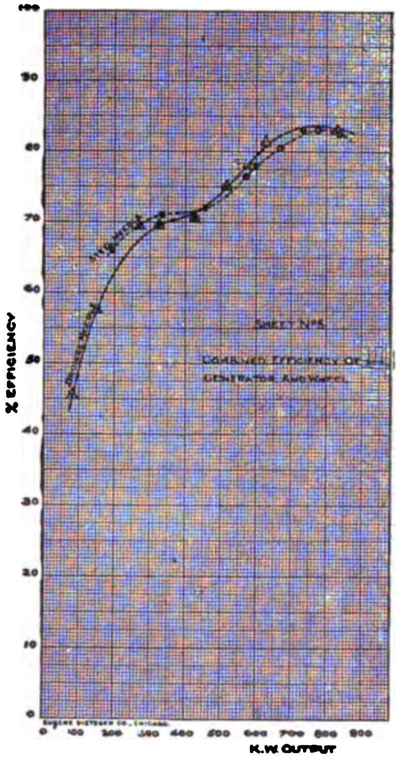

FIG. 5

From previous records the station attendant knows very closely the peak-load that is likely to occur within the hour, and, once an hour, or thereabouts, readjusts the size of the stream so that it will easily carry the peak-load. The governor then takes care of the load fluctuations, maintaining a constant speed at all times by deflecting more or less of the stream from the water wheel buckets. In this way a very great saving in water over the old deflecting nozzle when used alone is obtained.

By referring to the accompanying illustrative diagram (Fig. 6), it will be seen that the kilowatt hours may be represented by the heavily shaded area within the load curves. The lighter shaded space, including the heavy shaded area indicates the relative quantity of water used by this method to obtain the required output—whereas the very light shaded rectangular area, between the straight line drawn horizontal to the base and passing through the extreme peak, indicates the quantity of water which would be used by a deflecting nozzle only for accomplishing the same power output.

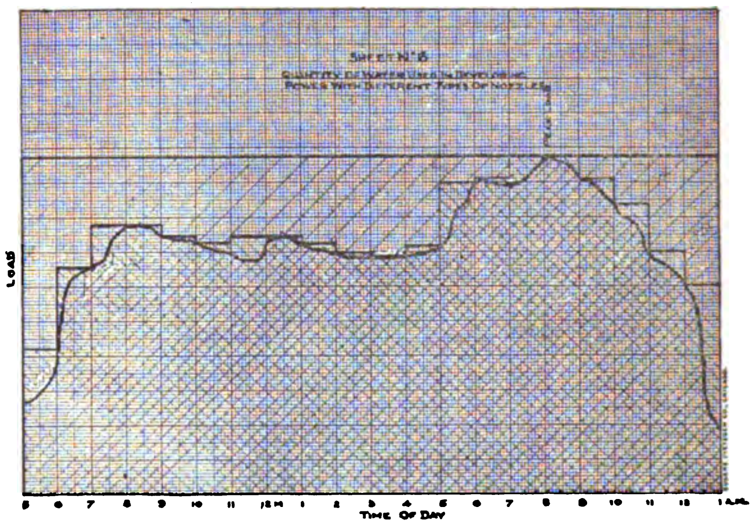

Fig. 6.

It is obvious that the best possible regulation and water economy could be effected without shock to the pipe-line if the needle is moved very slowly and follows the action of the governor, closing off some of the water whenever the governor has deflected the nozzle, or opening quickly if the governor calls for more power. The quick opening will not interfere with our pipe safety, whereas quick closing by the needle would be disastrous to a long pipe-line under high pressure. With the hand operated needle and automatic governor operated deflecting nozzle, this can only be accomplished to a limited degree, as the station attendant cannot be expected to remain at the hand wheel and adjust the size of the stream for frequent governor changes. In some of the most recent plants being constructed we are installing an automatic device for accomplishing this result. This device depends upon the action of the governor before starting its operation and, in combination with the governor, secures the best possible regulation, pipe safety, and water economy. The load curve and water quantity curve being almost synchronous, the quantity of water used is about proportional to the kilowatt hours' output, and exactly so if we leave out of consideration the partial load efficiency of the apparatus. These partial load efficiencies are, however, a very small item in a station employing a number of units, and the governors should be adjusted so that they follow each other in action—all but one unit being run fully

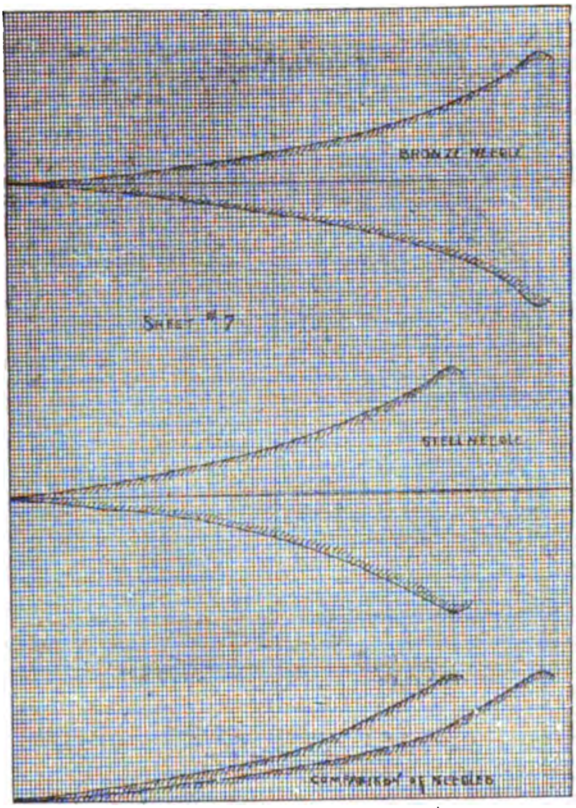

FIG. 7.

loaded, and governing being accomplished on the remaining unit. A small falling off at partial load efficiency on the unit doing the governing will then represent but an extremely small reduction in the gross efficiency in the whole station.

The needle nozzle is an extremely satisfactory device in actual operation when well designed and constructed, and the accompanying photograph (Fig. 12) of the jet leaving the nozzle under a pressure of 1923 ft. is interesting as being probably the first instance on record where the spouting stream under anything like so high a water pressure has been photographed.

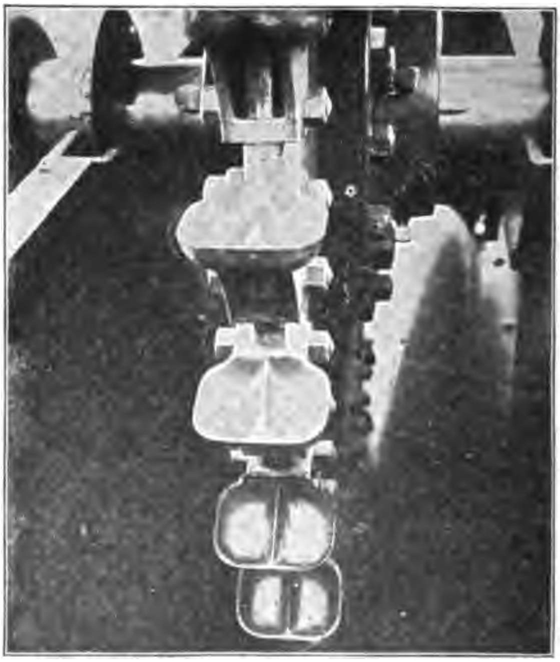

FIG. 8.—Type of tangential water wheel buckets used in the experiments; one with paint partially washed out to indicate the path of the water-jet over the surface during normal operation.

Fig. 8 shows the series of buckets on one of the wheels, one of which the writer painted with a coat of asphaltum varnish.

After allowing it to dry for two hours, he put the wheel in operation. The wheel ran at normal load, developing about 750 k.w. for about twenty hours before being again shut down. The bucket with the paint still remaining on it is clearly shown in the photograph. The location of the remaining paint clearly shows that the water, being discharged from a properly designed and installed wheel with this type of bucket, comes from the sides of the bucket and not from the front or back.

For obtaining reliable data for use in the future design of water wheels some very careful measurements were made on the efficiency and output of these wheels and the results are appended herewith in full.

Although the plant is being used for regular service, it is to some extent in an experimental condition; as, in spite of the high efficiency obtained, some changes are being made with a view, if possible, of still further increasing this. It will be understood that the efficiencies given and exceeding 86 per cent. are the gross efficiencies of the water wheel equipment, including the losses in the gate-valve and nozzle, the windage of the wheel, and such slight losses as occur in the buckets. When we consider that the total losses of this type of water wheel apparatus summed together amount to but a little more than 13 per cent. of the theoretical energy in the water, it will be readily appreciated that the results are extremely high, and can scarcely be surpassed by any other prime mover. The thoroughly satisfactory and continuous operation obtainable from such a tangential water

FIG. 9.—Main weir with hook gauge measuring apparatus.

wheel plant, makes it by far the most satisfactory power known for electric transmission. The maintenance and repair expenses for a plant of this character are almost negligible.

The units are separately excited from a generator driven by an independent water wheel and from a separate pipe-line, supplying only the exciter wheels during the test.

The object of the tests was to determine the efficiency of the wheel for different loads and styles of nozzle-tips.

ARRANGEMENTS FOR TESTS AND OBSERVATIONS.

All the water delivered by the wheel under test, as well as that delivered by the exciters, was passed over a rectangular weir of ample capacity. The discharge from the exciter alone was passed over another rectangular weir first, hence the water used by the wheel under test was deducted from the difference of flow over the two weirs. The output of the wheel was determined by the electrical output of the generator, whose efficiency was given by the manufacturer down to half-load.

FIG. 10.—Exciter measuring weir and hook gauge measuring Apparatus. This photo also shows the still water back of the main weir.

The effective head on the wheel was determined by the survey of the pipe-line corrected by the frictional drop as deduced from the dimensions of the pipe-line. This correction is so small as to be almost negligible for the quantities used, in fact a one thousand lb. gauge located forty feet above the nozzle showed no appreciable change between the static head, and the effective head when one unit was running full power. Still the correction has been made whenever appreciable.

The large weir used for measuring the combined water of the main water wheel and exciter, was well constructed and located, though rather too wide for the quantities used. The bay above was so large as to make the velocity of approach inappreciable. The small weir for measuring the exciter water was not so well located, but as its flow was absolutely constant, it was checked by the large weir when the main wheel was shut off. Considerable difference was observed between the measures of this latter quantity as given by the two weirs, therefore that deduced from the large weir has been adopted in the following calculations.

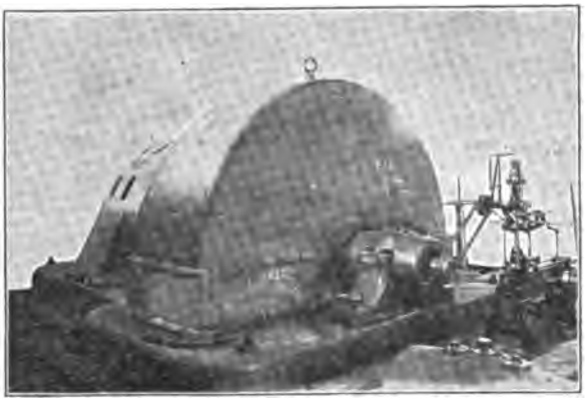

FIG. 11.—Water-wheel housings mounted on generator bedplate, hydraulic governor and connections and floor stand for controlling needle-nozzle.

The output of the switchboard was measured by two wattmeters, each of which gave the whole output. One of these was an indicating wattmeter, and the other an ordinary recording instrument. The results as given by the two did not agree for all loads, being about equal at 400 k.w., above this the latter reading in excess, and below the former. The comparison of the two instruments is shown in Sheet 2. In the calculations which follow, the results given by the recording instrument have been taken, that being considered the more reliable.

The efficiency of the generator is taken as given by manufacturer as:

95.6% full-load;
95.0% three-quarter load;
92.1% half-load.

Calling the generator efficiency E, we have—

$$\text{H.P. Wheel Input} = \frac{E.H.P.}{E} - (\text{Exciter H.P.})$$

Fig. 12.—High-pressure water jet issuing from the needle-nozzle, under a head of 1923 feet.

As the field excitation of the machine is 97 amperes, at 70 volts, about 6.8 k.w. are lost in the field, and the equation becomes:

$$\text{H.P. Wheel Input} = \frac{E.H.P.}{E} - 9.$$

Wheel efficiencies depending on switchboard instruments cannot be considered as absolute and can only show in a general way the relation between efficiencies under different conditions.

RESULTS.

The following constants and formulæ have been used in the calculations:

Static head = 1923 feet.

Width of large weir = 8 ft. 11/64 in.

Width of small weir = 4 ft. ¼ in

The quantity of water has been computed by Smith's formula:

$$Q = \tfrac{2}{3}\, c\, b\, h \sqrt{2\, g\, h}$$

$$= \tfrac{2}{3}\, c\, b \ \sqrt{29\, h\, \tfrac{3}{2}}$$

c being taken from Smith's tables.

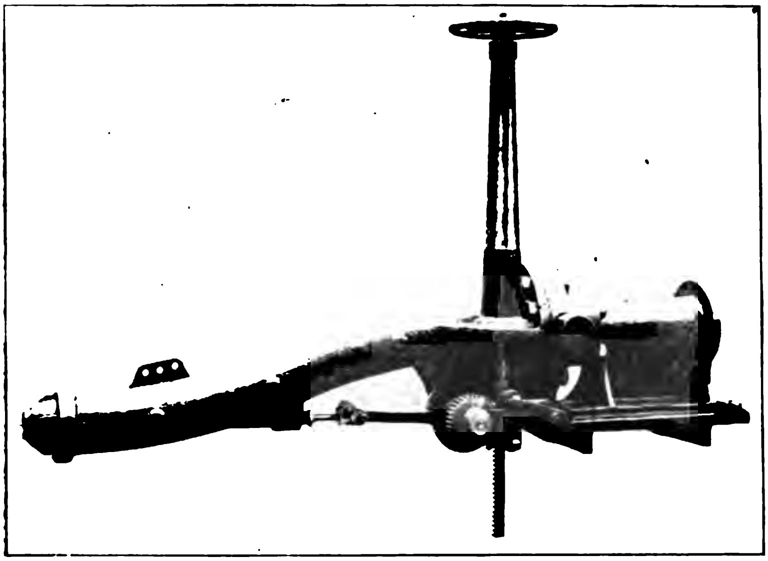

FIG. 13.—Combination deflecting and needle-nozzle, and needle operating connections of open-hearth carbon steel castings, annealed.

The available power back of the nozzle is taken from:

$$\text{H.P.} = 0.1134\ \text{Q.H.}$$

In the electrical horse-power output on the switchboard, correction has been made of 4 h.p. used to drive the blower, which was not recorded on the meters.

Three tests were made: First, a run on a 2″ tip with bronze needle; second, a run on a 2″ tip with a steel needle, and, third, a single observation on a 2⅛″ tip, with a steel needle.

Since the efficiency of the generator is not known below half load the results of the combined efficiency of the wheel and generator are given throughout the whole range.

Sheet 1 shows the curve of generator efficiency.

Sheet 2 shows the relation between the readings of the two wattmeters.

Sheet 3 shows the efficiency of the wheel to half-load for the first run, using the bronze needle.

Sheet 4 shows the efficiency of the wheel to half-load for the second run, with steel needle.

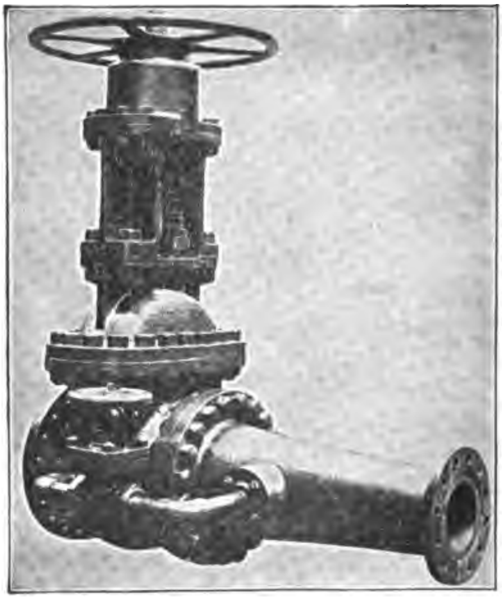

Fig. 14.—10″ Roller bearing gate-valve and connections put together with forged and turned steel bolts in reamed holes for the working pressure of 1923 feet.

Sheet 5 shows the combined efficiency of the wheel and generator throughout the whole range, with both needles.

The difference between the results with bronze and steel needles is due to the very slight difference in curvature and not in any way to the difference in material. The results show the necessity for very careful calculation to establish the most efficient shapes of needle and tip. When once obtained the efficiency is not only higher when the parts are new but is retained, also, for a much longer time, just as would be expected; less energy being expended in eddy currents that are an invariable cause of wear

It is to be regretted that, in taking these measurements, only commercial instruments were available. These, however, were new and in the best possible condition, and there is no reason to believe that the readings are not absolutely correct. It is unfortunate, however, that they could not have been specially calibrated for the work.

In using the recording wattmeter as a basis for efficiency determinations, it should be borne in mind that this is an instrument that has been specially manufactured for recording the kilowatt hours sold, and is therefore carefully calibrated in the factory, and probably more reliable than an instrument used for indicating the load on the machines only.

In the accompanying tables the amperes recorded are taken from one leg only of the three-phase circuit on which the load was well balanced. Any slight out of balance condition would, however, not materially affect the result as the ampere readings are used only to determine the power-factor.

The voltmeter readings should be multiplied by 7, as that was the ratio of its switchboard transformer.

FIRST TEST.
2" Tip, Bronze Needle.
Results (Hydraulic).

Time	Weir	Weir (Feet)	C.	Total Q.	Net Q.	Friction Head	Effective Head	H.H.P.
11.35	5-1/16	.422	.616	7.23	6.15	5 ft.	1918	1137
12.27	4-17/32	.3775	.618	6.12	5.04	3.5 ft.	1920	1097
1.00	4-11/32	.362	.619	5.78	4.70	3.5 ft.	1920	1024
1.20	4-3/32	.341	.621	5.285	4.205	2 ft.	1921	916
1.30	3-13/16	.318	.622	4.78	3.70	1.5 ft.	1922	807
1.45	3-11/32	.279	.625	3.945	2.885	1 ft.	1922	624
1.57	3-5/64	.256	.627	3.48	2.40	0	1923	524
2.10	2-29/32	.242	.628	3.205	2.125	0	1923	409
2.15	2-9/16	.213	.631	2.66	1.58	0	1923	345
2.20	2-17/64	.189	.634	2.23	1.15	0	1923	251
2.30	1-27/32	.1535	.640	1.65	.57	0	1923	124
3.00	1-3/8	.1145	.650	1.08	0	0	1923	0

FIRST TEST.

2" Tip, Bronze Needle.

Results (Electrical, etc.).

Time	Indicating Wattmeter	Recording Wattmeter		Power Factor	Efficiency of Generator	Wheel Input	Efficiencies.	
		K.W.	E.H.P.				Wheel	Combined
11.35	780	(826)	(1107)	.88	95.6	1153	86.2	82.8
12.27	640	665	891	.88	95.3	931	84.9	81.8
1.00	575	593	795	1.	95.1	832	81.2	78.0
1.20	500	510	684	.98	94.4	720	78.6	75.1
1.30	425	423	567	.92	93.3	603	77.2	70.7
1.45	330	320	429	.83	90.5	474	76.0	69.4
1.57	290	269	360					69.5
2.10	260							
2.15	180	146	196					57.9
2.20	125	82.	110					45.5
2.30	50	—	—					—
3.00	37.5	0	0					—

FIRST TEST.

2" Tip, Bronze Needle.

Time	Weir	Indicating Wattmeter	Recording Wattmeter		Volts	Amperes	Speed
			Time	Rev.			
11.35	5-1/16	780	—	—	108	620	425
12.27	4-17/32	640	2 min.-10 sec.	8	108	500	432
1.00	4-11/32	575	3 " 2 "	10	108.5	450	434
1.20	4-3/32	500	3 " 32 "	10	108.5	395	—
1.30	3-13/16	425	3 " 24 "	8	108.5	350	428
1.45	3-11/32	330	2 " 49 "	5	108	295	428
1.57	3-5/64	290	3 " 21 "	5	108.5	255	—
2.10	2-29/32	260	— " —	—	107.5	240	—
2.15	2-9/16	180	1 " 14 "	1	108	205	431
2.20	2-17/64	125	2 " 12 "	1	108	200	—
2.30	1-27/32	50	— —	—	108	180	228
3.00	1-3/8	37½	— —	—	—	—	—

SECOND TEST.

2" Tip, Steel Needle.

Observations.

Time	Weir	Indicating Wattmeter	Recording Wattmeter		Volts	Amperes	Speed
			Time	Rev.			
5.10	1-25/64	375	—	—	108	0	—
5.15	2-23/32	215	2 min.-49 sec.	3	108	180	428
5.22	3-3/8	340	2 " 43 "	5	108	255	—
5.30	3-15/16	450	2 " 46 "	7	108	350	430
5.40	4-5/16	560	3 " 9 "	10	108	430	432
5.55	4-9/16	635	2 " 42 "	10	107.5	500	433
6.00	4-47/64	700	1 " 58 "	8	108.5	540	—
—	4-7/8	750	2 " 20 "	10	109	580	—
11.35	5-3/32	787	3 " 15 "	15	107	615	—

SECOND TEST.

2" Tip, Steel Needle.

Results (Hydraulic).

Time	Weir	Weir Feet	C.	Total Q.	Net Q.	Friction Head	Effective Head	H.H.P.
5.10	1-25/64	.1158	.649	1.096	0	0	1923	0
5.15	2-23/32	.226	.633	2.91	1.814	0	1923	395
5.22	3-3/8	.281	.624	3.98	2.889	1	1922	630
5.30	3-15/16	.328	.621	5.00	3.904	2	1921	851
5.40	4-5/16	.359	.619	5.705	4.609	3.5	1920	1005
5.55	4-9/16	.380	.618	6.20	5.104	3.5	1920	1112
6.00	4-47/64	.394	.617	6.54	5.444	4.5	1919	1186
—	4-7/8	.406	.617	6.84	5.744	5	1918	1252
11.35	5-3/32	.424	.616	7.28	6.189	5	1918	1347

SECOND TEST.

2" Tip, Steel Needle.

Results (Electrical, etc.).

Time	Indicating Wattmeter	Recording Wattmeter		Power Factor	Generator Efficiency	Wheel Input	Efficiencies	
		K.W.	E.H.P.				Wheel	Combined
5.10	37.5	0	0	—	——	—	——	——
5.15	215	192	257	.81	——	—	——	66.0
5.22	340	331	443	.99	91.0	482	76.5	71.0
5.30	450	455	610	.99	93.8	646	75.9	72.1
5.40	560	572	767	.99	95.0	799	79.5	76.7
5.55	635	666	892	.97	95.5	940	84.5	80.6
6.10	700	732	982	.98	95.6	1022	86.1	83.1
—	750	772	1035	.98	95.6	1074	85.8	83.0
11.35	787	831	1114	.98	95.6	1156	85.8	82.6

THIRD RUN.

2⅛" Tip, Steel Needle.

Observations.

Time	Weir	Indicating Wattmeter	Recording Wattmeter		Volts	Amperes	Speed
			Time	Rev.			
3.10	5-7/16	870	2 min.-2.5 sec.	10	108	680	430

RESULTS—(HYDRAULIC).

Time	Weir	Weir (feet)	C.	Total Q.	Net Q.	Friction Loss	Effective Head	H.H.P.
3.10	5-7/16	.453	.615	8.04	6.89	7.5	1916	1511

RESULTS—(ELECTRICAL, ETC.).

Time	Indicating Wattmeter	Recording Wattmeter		Power Factor	Generator Efficiency	Wheel Input	Efficiencies	
		K.W.	E.H.P.				Wheel	Combined
3.10	870	882	1181	.98	95.6	1230	81.4	78.2

DISCUSSION ON PAPER BY GEORGE J. HENRY, JR., AND JOSEPH N. LE CONTE, ENTITLED, "AN EFFICIENT HIGH PRESSURE WATER POWER TRANSMISSION PLANT."

MR. F. O. BLACKWELL:—The Redlands plant is the first three-phase power transmission plant in the United States. It had at first two 250 k.w. 2500 volt generators, operated by wheels under a 300 foot head, and a seven mile transmission; synchronous motors were used. Later, ahead of 800 feet was developed, and two 450 k.w. 11,000 volt machines were operated on a 30-mile transmission. This plant was connected in parallel with the Santa Ana plant, which supplied a transmission line 90 miles long to Los Angeles. The plant described in the paper operates under a head of 2,000 feet and has a capacity of 4,000 h.p., using the same water as the former plant. The generators are of low-voltage, the line pressure is 33,000 volts, and feeds into the same transmission lines to Los Angeles. The Los Angeles Edison Company controls seven power stations, located at points as far apart as 100 miles—all feeding the same transmission system, and operating practically as one station; they are now developing a new plant on the Kern River, of a capacity of 20,000 h.p. to operate at 60,000 volts and transmit 150 miles to Los Angeles. Thus the history of this system embodies the entire development of hydro-electric transmission in this country.

The diameter of the water wheel described in Mr. Henry's paper is 7 feet; that of the nozzle 2 inches. This ratio of 40 to 1 and the use of the needle nozzle probably account for the very high efficiency obtained — particularly at partial load. The original Redlands plant, under a 300 foot head, had an efficiency of less than 70 per cent. at full load and 30 per cent. at half load; this plant has an efficiency of 85 per cent. at full load and 75 per cent. at half load.

The regulation attained — about 2 per cent. — is extremely close—as good as the best steam engines. The curve of efficiency is peculiar, being high at full load, dropping off suddenly at three-quarter load, and then returning to the same efficiency at half load. The reason for this is not clear, but it is probably correct, since both tests show the same peculiarity. The water may spatter more at certain points, when the needle is thrust into the nozzle, than at others, and this may account for the lower relative efficiency at three-quarter load.

MR. H. A. LARDNER:—The pipe line of the Santa Ana plant of the Los Angeles Edison Company operates under a head of about 650 feet and is built of wrought iron pipe with flanged joints bolted together without provision for expansion. The head waters of the stream furnishing water for this and many other of the high head plants in California are in the region of perennial snow, and the temperature of the water is quite uniform throughout the year. Most of the pipe lines are buried, and on account of the uniformity in temperature of the water, no particular difficulty from expansion and contraction is experienced. Some of the pipe lines are anchored in two or three places where the condition of the rock permits, but as nearly all of them have a considerable curvature either in a vertical or horizontal plane, they are to quite an extent self-anchored when buried.

One plant in Colorado has a pressure pipe, operating under 1100 feet head, made of riveted wrought iron sections. The sections are lap-riveted together. This type of pipe has not many advocates, owing to the difficulty in making repairs.

The plant of the Standard Electric Company in California, operating under a head of 1600 feet, has a cast iron section in the pressure pipe for the upper one-third. This cast iron pipe has leaded bell joints and each bell is anchored by a concrete block which is firmly embedded into the rock of the mountain side.

The wheels employed in this plant have but one set of buckets. Some of the high head wheels, notably those of the 2000 k.w. of the Standard Electric Company, have two sets of runners and nozzles in the same casing. These runners are about 14 inches apart in the Standard Company's wheels and the nozzles are so controlled that they are operated very much as the author operates two generators—one nozzle remains full on its set of buckets down to half load while between half load and full load the other nozzle is thrown on or off to meet the demand of the load. If the load is less than half, the water is entirely shut off from one of the nozzles and the governor controls the remaining one. Needle valves are not used at the Standard plant, but I should think that with large units it might be an added economy to have not only a double nozzle but the needle valve as well.

It would be interesting to know the efficiency of the needle valve in different positions, and if this varies much, the addition of the two nozzles and sets of runners would tend towards a more efficient unit.

Mr. B. J. Arnold:—Engineers who practice in the East and Middle West have little to do with water power plants, and with them it is nearly always a question whether to use water power or put in a steam plant. Generally speaking, when the reduction of water power, due to the Winter period, is considered, it will be found desirable to put in a steam plant rather than a water plant, but this consideration does not apply to high pressure water power plants where the water supply is continuous, nor does it apply where the cost of coal is very high.

*A paper read at the 179th Meeting of the
American Institute of Electrical Engineers,
New York, September 25, 1903.*

ELECTRIC MOTORS FOR CENTRIFUGAL PUMPS AND FANS.

BY AUG. J. BOWIE, JR.

The rapidly increasing use of electric motors for driving centrifugal pumps and fans renders important the study of loads of this nature under the varying conditions encountered in practice. The possible loads which may thus be thrown on a motor, due to variations in speed, or in the head against which the pump or fan which it drives must operate, are serious enough to warrant careful consideration.

The problem of determining the proper capacity of a motor is not always easy to solve. The solution is too often the result of guesswork, and is liable to be seriously in error. In the case of direct-acting pumps working against a known head, the proper motor capacity can be easily calculated. The most economical size of motor for the purchaser, however, may not be solely determined by the possible loads, and their duration, which the motor may be called upon to carry. Particularly is this true where a flat-rate system is in vogue and where power is purchased at a price depending upon the rating of the motor and not upon the power actually used. This system of charging for power may lead to great abuse in the underrating of motors; on the other hand, it may work a great hardship on a purchaser of power who innocently uses a motor far larger than is necessary and who therefore pays for power that is not consumed. Several instances of the latter have come under the writer's observation, and in his opinion the system should be condemned. Where measurements of power are taken as a basis for determining the flat rate, such measurements should be taken under the average running conditions. A variation in these conditions may lead to a very erroneous system of charges in the case of centrifugal pumps and fans, as will be seen later.

For centrifugal pumps and fans the power required for operation at a rated speed and head is by no means all that need be known. One should also know the maximum load which can ever come on the motor when driving the pump or fan at the rated speed and under any possible head. The maximum may be far in excess of the rating.

The problem in case of centrifugal pumps and fans will be treated under the following three heads: (1), Constant speed and varying heads; (2), Changing speed with head varying directly as the square of the speed; and (3), Constant head and varying speed.

1. CONSTANT SPEED AND VARYING HEADS.*—The following treatment applies equally well to centrifugal pumps and to centrifugal fans, as the same laws govern the flow of air and water, but pumps alone will be considered. Represent by H the head generated by the pump. This is equal to the difference between the discharge and suction pressures plus the difference between the discharge and suction velocity heads. Represent by Q the cubic feet of water discharged per minute. The general equation expressing the relation between Q and H is, $H = A - B Q^2 + CQ$. where A, B, and C are constants.

This is the equation of a parabola, and it will approximately represent the actual curves obtained in practice. Back-slippage through the running rings of the pump has not been taken into account in the above equation, and will account in part for discrepancies between theoretical and actual results.

The pressure exerted by the pump is a maximum when the first derivative of H with respect to Q, $- D_q H = 0$. Hence, when $2 B Q = C$, $Q = \frac{C}{2B}$, and $H = A + \frac{C^2}{4B}$, is the maximum value.

Let $W_0 =$ output of pump in watts. $W_0 = KHQ$, K being a constant. $W_0 = KQ (A - BQ^2 + CQ)$. This is a maximum when $DqW = 0$, or

$A - 3BQ^2 + 2CQ = 0$. $Q = \frac{C}{3B} \pm \sqrt{\frac{A}{3B} + \frac{C^2}{9B^2}}$, corresponding to $H = \frac{2}{3}A + \frac{1}{3}CQ$. In some pumps the constant C is so small that it may be disregarded. In this event the maximum head is obtained at zero discharge and is equal to A. The

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*The compressibility of air is not taken into account, as the pressures at which fans are run are so light that this is a matter of small importance, maximum output of the pump is obtained at a head of $\frac{2}{3}A$. The relative values of C and B determine the nature of the output curve of the pump and the maximum obtainable pressure. If B be fixed, the greater the value of C the greater will be the capacity of the pump. If C be fixed, the less the value of B the greater will be the pump capacity. However, the relative values of C and B will have a very important bearing on the ratio between the maximum power required to run the pump, and the power required to run it at the point of highest efficiency, or at the point of maximum output.

The quantity $\frac{C}{B}$ is influenced largely by the angle which the vanes of the pump make with the radial at the external periphery, as well as by the width of the face of the runner. However, it is beyond the scope of this paper to enter into a discussion of the design of pumps, other than in a general way, so as to show the effect of the design upon the maximum power required to drive the pump. Usually this power will increase as the effective head of the pump decreases. This would naturally be expected as long as the energy output of the pump is on the increase, but after the latter starts to decrease it might be considered natural to look for a decrease of the driving power. When B is fixed, the smaller the value of C the less will be the tendency of the pump to require additional power to drive it at heads lower than its rated capacity, and the higher the value of C the greater will this additional power become. When C is fixed, the reverse holds true for B.

A centrifugal pump, when operated at too low a head, shows a very low efficiency. In general, however, with a well-designed pump, the range of efficient operation for a constant speed is fairly broad. The principle point which the writer wishes to bring out in this connection is the danger of overloading a motor through too low a head. A manufacturer will usually guarantee a certain efficiency and input for a pump at its rated load, but will say nothing concerning the power repuired to drive it at heads lower than that specified by the purchaser. The question may arise, why not give a pump the proper speed for a given head. This is frequently impracticable, since pumps must often be installed to work under widely varying heads, where it is not an easy matter to change the speeds. Oftentimes the heads to which the water must be elevated may vary practically from zero to the maximum head against which the pump will deliver. In some cases these overloads may be of long duration, and a sufficiently large motor should be installed. On the other hand, the maximum load will often be only of short duration, as for example in the case of pumping from a well, particularly where there is a pit in connection with it, which is partially filled with water. Generally it will not take the pump long to lower the water considerably; and, as a rule, then, the duration of overload will be brief.

The behavior of centrifugal pumps may be represented very completely by four curves. These curves are based upon an absolutely fixed speed. Corrections for variations from this speed may be made without difficulty. These curves have, in each case, for abscissæ, the volumes of the fluids delivered in a fixed time interval; for ordinates they have respectively, head, watts input to pump, watts output from pump, and pump efficiency.

The last two curves determine the proper rating of the pump. In general, the maximum efficiency occurs before arriving at the point of maximum output. The proper rating is somewhat indefinite, as will appear from the appended curves obtained in practice. The natural tendency of a manufacturer is to rate his pumps as high as possible. Still, he does not care to go far beyond the point of maximum efficiency at the full-load rating.

The accompanying curves show the results of tests on two fans with the same casing but with different runners. In the first set $\frac{C}{B}$ is smaller than in the second set. According to the curves, the first fan is of smaller capacity, but of higher efficiency than the second. Particularly noticeable is the curve of watts input, which in the first case shows a decided concavity towards the X axis, shortly after passing the maximum output of the pump. On the contrary, in the second case the corresponding curve becomes slightly convexed towards the X axis, and requires far more power under low heads. Thus the ratio of maximum outputs is 1.15, and the ratio of maximum inputs, within the range of the tests, is 1.68. These fans represent by no means extreme conditions. In the case of the second fan, if it should be called upon to operate under the lowest head tested, and if it were rated at the point of maximum efficiency and a corresponding motor were installed, then this motor would be liable to an overload of 89%.

2. Changing Speed with Head Varying Directly as the Square of the Speed.—If a centrifugal pump delivers Q cubic feet of water per minute, against a pressure of H feet while running at R revolutions per minute, and then if the speed be altered to $R_1=KR$, it will deliver $Q_1=KQ$ cubic feet per minute against a pressure $H_1=K^2H$ feet. If $W=$ watts output of pump in the first case, and $I=$watts input to pump, then $W_1=K^3W$, and $I_1=K^3I$. These equations follow from the proportionality between the head generated and the square of the speed, and because, when the volumetric output varies directly as the speed, the relative angles of motion of the water are not altered. Furthermore, all frictional losses vary as the cube of the speed, and all volumetric leakage losses vary as the speed. Hence it follows that increasing the speed of the runner, where the effective head varies as the square of the speed, will result in increasing the capacity of the pump directly as the speed, and increasing the power input and output directly, as the cube of the speed. The conditions presupposed in this case; namely, that the head varies as the square of the speed, is the condition which exists in the case of ventilating fans, where the head is used up in friction in the pipe, and in the velocity-head of discharge from the pipe. This velocity-head, and also the friction head vary as the square of the discharge from the pipe.

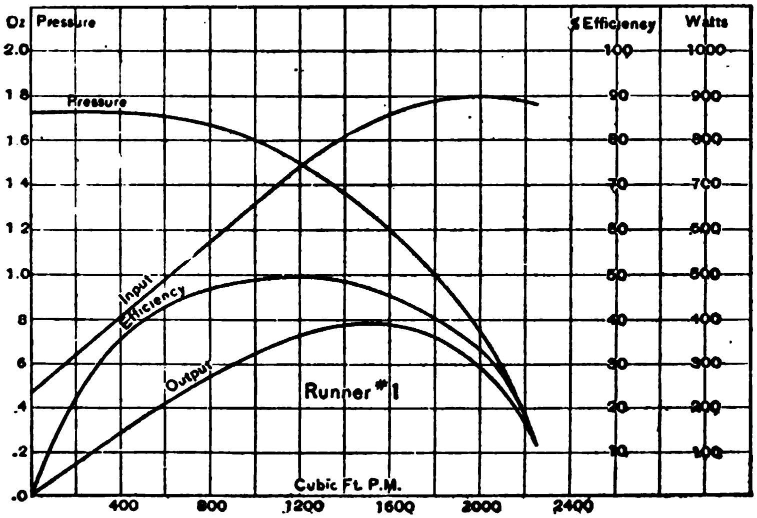


Fig. 1

What concerns the motor capacity particularly is the fact that the power varies directly as the cube of the speed. Hence the $I^2 R$ loss in the armature varies as the sixth power of the speed.

3. CONSTANT HEAD AND VARYING SPEED.—This is the condition which exists when pumping against a fixed lift, when the velocity-heads lost at entrance and discharge, and when the frictional losses in the pipe may be disregarded in comparison with the lift.

In this case, and likewise in case 2, the characteristic curves of a pump under variation of speed can be obtained from those at another speed in the following manner: Let S = speed of pump at which curves are known, H = head; W_1 = watts input; W_0 = watts output; E = efficiency; rate of discharge = Q. Then if the speed be changed to $K S$, the corresponding points on the new curves for this speed will be: $K^2 H$ = head; $K^3 W$ = watts input $K^3 W_0$ = watts output; E = efficiency; $K Q$ = rate of discharge.

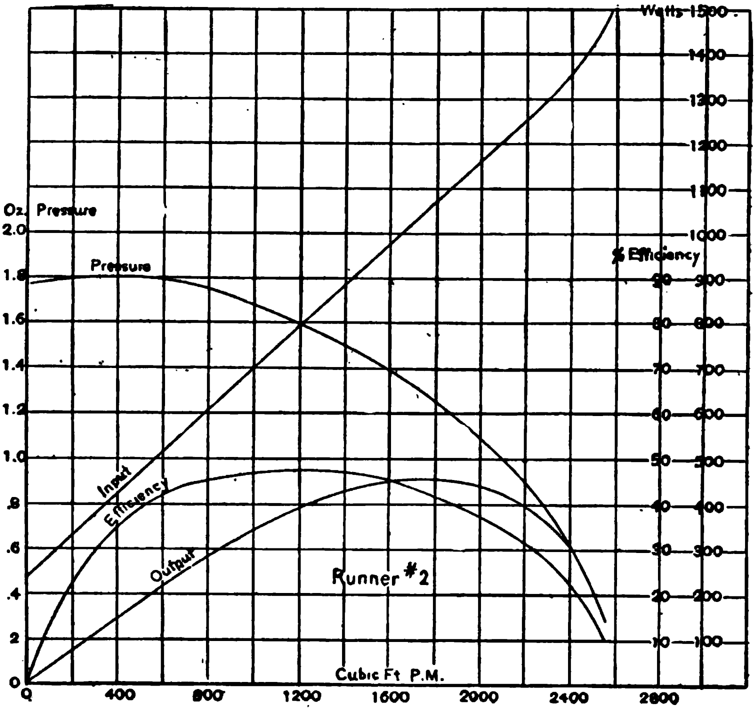


FIG. 2.

It is evident that the apparatus of case 3 will operate at a point situated farther along on the curves than that of case 2; the result being a greater delivery of water, and usually a greater input to the pump. In general, this input will vary faster than the cube, but not so fast as the fourth power of the speed,—as an approximation, say as the 3.5 power of the speed. This makes the $I^2 R$ loss in the armature vary as the seventh power of the speed. Thus 10% increase in speed represents 40% increase in power and 96% increase in the $I^2 R$ loss in the armature. From this it may be seen what an extremely large effect speed-variation has on motors driving centrifugal apparatus. There is perhaps no other form of apparatus so sensitive to change of speed in its power consumption. The effect which a steady pump load has in holding the voltage constant by preventing the racing of generators is thus explained.

If centrifugal apparatus be provided with induction or synchronous motors, then the speed is practically fixed by that of the prime mover, so that the maximum load for the motor with a given pump or fan is determined.

Speed control of direct current motors by variation of field resistance has a limited range in practice and has many points which tend to make it objectionable for the best conditions of commutation. Even at best there will be considerable field distortion at the high speeds. The effect of a load which would increase as the cube of the speed, and even faster, would seem to limit still further the allowable speed variation to be obtained in this manner. In view of these facts it is well to provide a motor of ample size for such work, and at the same time to see that the field rheostat cannot cut in enough resistance to overload the motor. As has been shown, the volumetric output of a centrifugal pump varies directly as the speed of revolution. In spite of this fact, many manufacturers rate their pumps at a fixed volumetric output, and publish a list of suitable speeds for different heads under which it may be desired to operate the pump. In some cases the highest speed given in these lists is three or more times as great as the lowest speed. Such misinformation leads to a great deal of trouble and cannot be too strongly condemned.

In regard to the statement previously made, that the efficiencies of pumps and fans were independent of the speed, proper changes being made for head and discharge, no consideration was taken of the effect of unbalance of the runner or of bearing or stuffing-box friction. These, of course, would modify the results obtained. Lack of proper running balance is very apt to cause serious loss of power.

DISCUSSION ON PAPER BY AUGUST J. BOWIE, JR., ENTITLED " ELECTRIC MOTORS FOR CENTRIFUGAL PUMPS."

MR. H. G. STOTT:—The experience of the speaker is that the variation in the power required by a centrifugal pump working under different heads, is so complex that it is impossible to make any flat rate for electric power for this service; the best method of charging is by wattmeter. As applied to barometric condensers where a variable speed is demanded, centrifugal pumps, driven by shunt wound, direct current motors, do not give good service. In starting a condenser without a vaccuum, a speed at least 15 per cent. greater than normal speed is required; when a partial vacuum has been established, a heavy overload comes on the motor, and in all probability the circuit-breaker opens and the pump stops. When variable speed or variable head is required with a centrifugal pump, a steam engine with a throttling governor is far preferable.

MR. F. O. BLACKWELL:—A particularly good feature of the reciprocating pump is that it can be operated at any speed under a constant head and will provide for a wide range of capacities. With a centrifugal pump on an ordinary supply system, if the water is not drawn off, the head increases until the pump delivers no water; but when the water is drawn off, the pressure drops, and the pump immediately begins to deliver water. A variation of perhaps 20 per cent. in the back pressure on a centrifugal pump will determine whether the pump will work at full capacity or deliver no water; or, conversely, a variation of only about 20 per cent. in speed is required between delivery of no water and full capacity; from this point of view, the centrifugal pump is ideal for electrical purposes; it also has the advantage of operating at high speed. Centrifugal pumps for very high heads, with several sets of runners, each feeding into the next, is a very promising development, and in the opinion of the speaker, will in time replace the reciprocating pump altogether. Such pumps are now made with seven or eight runners, each lifting the water 100 feet, thus giving a total lift of 700 or 800 feet, with an efficiency of 80 per cent.—a figure practically equal to that given by the reciprocating pump.

A paper presented at the 180th Meeting of the American Institute of Electrical Engineers, New York, October 23, 1903.

THE CONDITIONS GOVERNING THE RISE OF TEMPERATURE OF ELECTRIC RAILWAY MOTORS IN SERVICE.

BY CARY T. HUTCHINSON.

In a former paper read before the INSTITUTE (TRANS. AM. INST. E. E., Vol. XIX., p. 129), I described a method for determining the motor-capacity and energy required to make any schedule speed for a run of any distance, with electric motors. Since that time I have extended the method to include the predetermination of the rise of temperature of the motor when those constants of the motor are known, upon which the rise of temperature depends.

In that investigation the time required for each of the three periods of the "type-run," shown in Fig. 1, was first determined; this was an algebraical problem, the solution of which involved

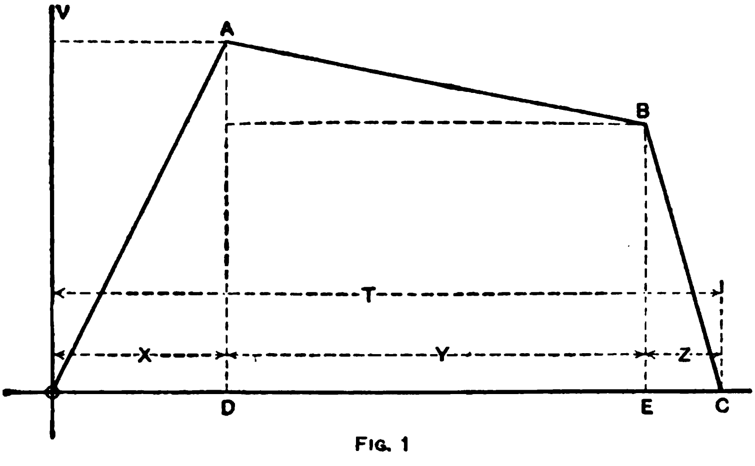


FIG. 1

the initial acceleration (a), the coasting retardation (b), the retardation after braking (c), the length of the run and the average speed from start to stop. These equations are:

$$\begin{aligned} x/T &= 2\,A_0/a - K_1\,(A_0 - A)^{1/2} \\ y/T &= \qquad\quad K_2\,(A_0 - A)^{1/2} \\ z/T &= 2\,A_0/c - K_3\,(A_0 - A)^{1/2} \end{aligned}$$

in which K_1, K_2, K_3 and A_0 are simple functions of (a), (b) and (c) only; x, y and z are respectively the times of initial acceleration. coasting and braking, and T the total time, as shown in Fig. 1. The only quantity occurring in these equations other than the three accelerations, (a), (b) and (c), then, is

$$A = V/T = 0.682\,L/T^2$$

T being the time and V the average speed from start to stop; the form cf the equation shows that all runs having the same values of (a), (b), (c) and A will be made in the same proportionate time for the different periods, *i.e.*, the same fraction of the total time will be required fcr accelerating, coasting and braking. In other words, all runs having the same value of the accelerations and of $A = V/T$ are represented by the same figure, with merely a change in scale for the different lengths of run, the ordinates and abscissas being proportional to $L^{1/2}$.

This quantity, A, reduces the variables from three—V, L and T, to two—A and L. A is a convenient quantity to use as independent variable for the curve-sheets; it simplifies the presentation, since all runs having the same values of A, (a), (b) and (c) require the same energy per ton-mile, independent of the length of run or the average velocity, and require a motor-capacity directly proportional to the square root of the length of run—that is, directly proportional to the time from start to stop.

Moreover, all values of A occurring in practice can be included between the values of 0.15 and 0.35—a relatively small variation whereas variations in V, L and T cover a much wider range.

It is to be remembered that the previous investigation, as well as this one, assumes a straight, level track, constant train friction and constant braking force. These assumptions are necessary to any general treatment, since curvature and gradients are arbitrary. I have, however, in part, developed a method for making the necessary allowances for curves, grades and variable train friction, in the form of corrections to the values found for the corresponding simple case.

These equations involve four quantities, of which two—(b) and (c)—are assumed to be constants and two—(a) and A—

the variables. The solution of the equations is best given by curve-sheets, with x/T, y/T and z/T as ordinates, and A as abscissas; a separate curve is required for each value of (a). CS 1 is plotted with

$$(b) = .15 \text{ mph/sec.} = 13.6 \text{ lb. per ton}$$
$$\text{and } (c) = 2.0 \text{ mph/sec.} = 182 \text{ lb. per ton;}$$

(c) is the total retardation after braking, including train friction. This curve-sheet is similar to CS 2 of the first paper, save that there the values, (b) = .2 and (c) = 3.0 mph/sec.; were used.

Fig. 1 shows the type case, with three constant accelerations; Fig. 2 the actual case, in which acceleration on the motor-curve is added to the constant initial acceleration; Fig. 2 then involves the characteristics of the motor used. CS 5 of the first paper gave the average speed- and torque-curves of a number of tramway motors in common use; I have since added other motor-curves, and in CS 2 show average motor-curves, which represent with practical accuracy the torque and speed relations of any General Electric or Westinghouse motor, throughout the range of ordinary operation. The extreme difference between the speed of any motor of either company and the speed on this curve-sheet for a given torque is greatest at the high speeds, but within the range of ordinary operation this variation is less than 5 per cent.

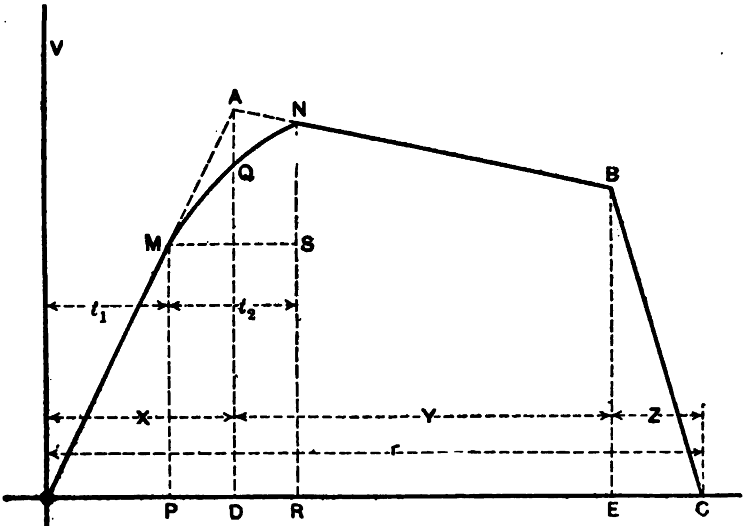


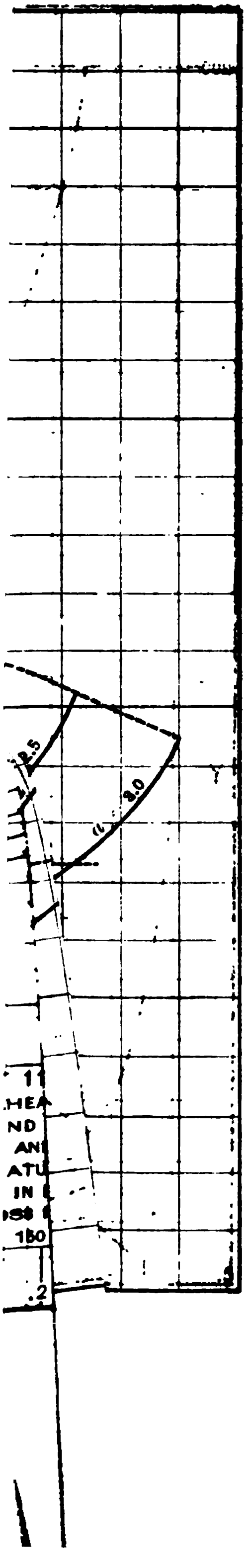
FIG. 2

It is necessary to assume the same motor performance in order that the variation in energy consumption and motor-capacity required by the different schedules, when made with various initial and motor accelerations, may be shown independently of variations in characteristics of the motor. If one assumes other motor-curves, the methods outlined here can be applied by making certain corrections; but, as a matter of fact, the small variations in the shape of the motor-curve are of comparatively slight consequence in the final results.

The efficiency of different motors varies through a much wider range than do the speed and torque; but the efficiency is used only in connecting the input and output, and not in determining heat losses, which are the subject of a separate consideration; hence considerable differences in efficiency curves are of minor consequence.

Here, as in the first paper, the datum point for these motor curves is the load determined by the " hour-rating,"—that is, the load the motor will carry for one hour with a temperature rise of 75% C. when tested on the stand, with covers off; this value is assumed to be the commutation-limit of the motor-capacity and all the results of the investigation are expressed in terms of the input donated by the datum point; therefore it only remains to determine the conditions of a run which will give the limiting temperature elevation when the motor is used at this particular input. The hour-rating for the maximum input is not unduly conservative; it leaves a margin for greater power on curves, grades and for emergencies.

CS 3 and CS 4 give energy and motor-capacity in terms of through-acceleration A; they are the same as CS 13 and CS 14 of the first paper, except that here the abscissas are through acceleration with the motor-curve instead of the corresponding through acceleration with the type-curve; that is, the quantity A_m of the first paper is used as abscissa instead of the A of that paper, but is designated A; and that the motor-capacity is given for a run of one mile. This change simplifies the use of the curves, in that it makes it unnecessary to add corrections to the value of A calculated from the data given for the run. CS 3 then gives directly the energy per ton-mile for any run and for initial accelerations from 0.6 to 3.0 mph/sec., and for a train friction of 13.6 lbs. per ton, equivalent to (b) = .15, a retardation after braking equivalent to 2 mph/sec., and all for an acceleration on the motor-curve to a speed of 50 per cent. greater than the speed with all resistance out.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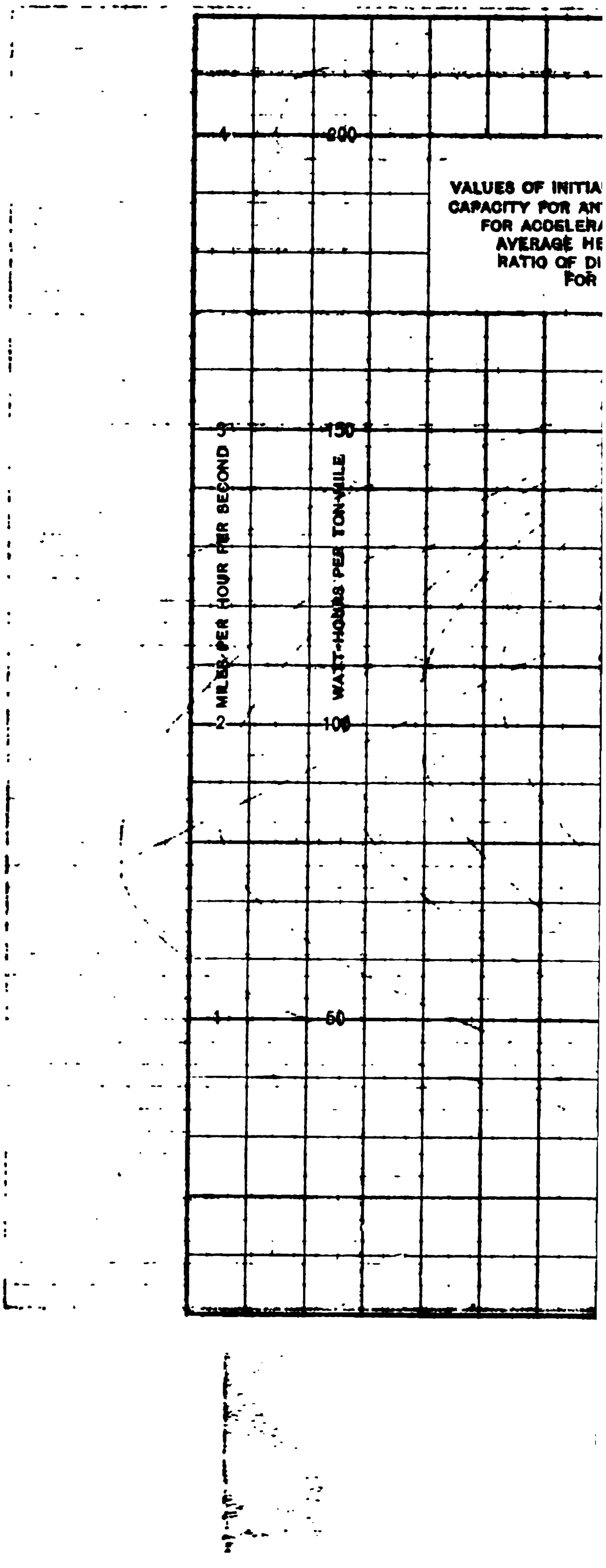
VALUES OF INITIA
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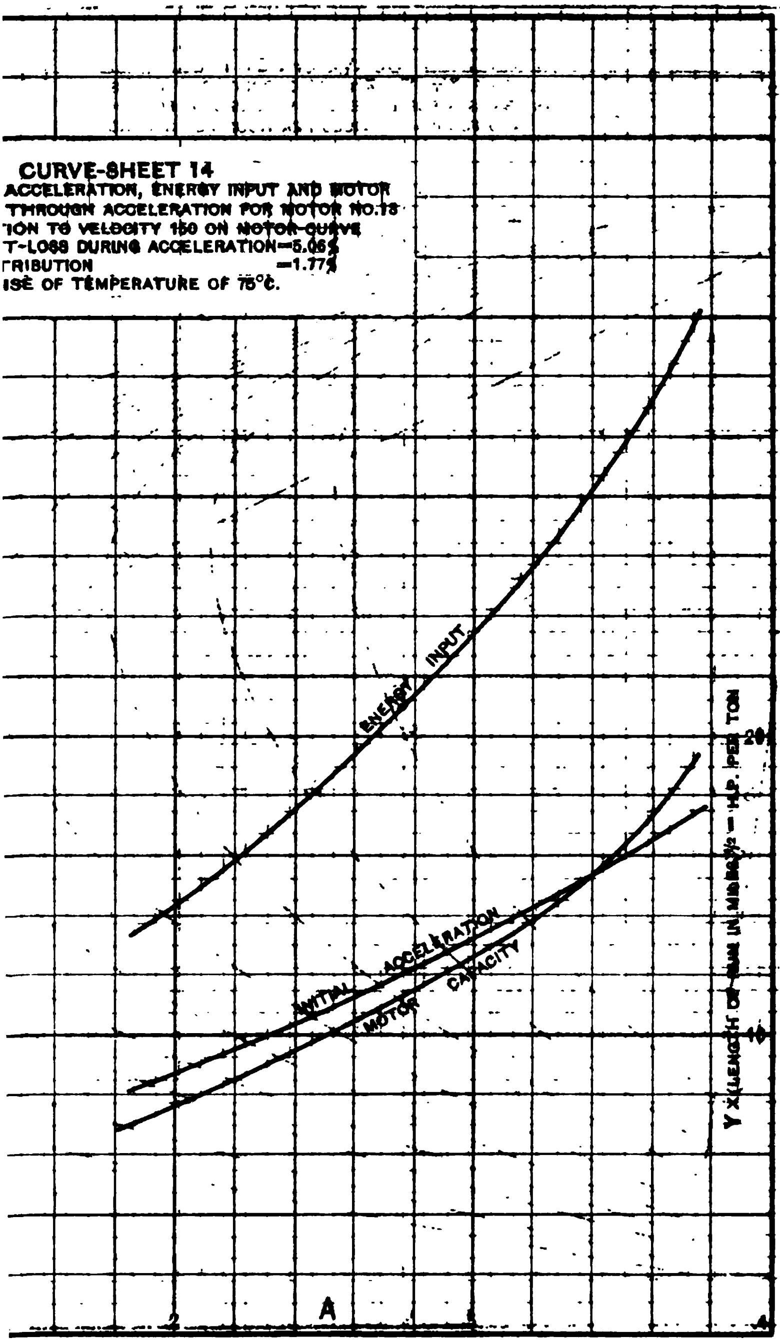
MILES PER HOUR PER SECOND
WATT-HOURS PER TON-MILE


CURVE-SHEET 14
ACCELERATION, ENERGY INPUT AND MOTOR
THROUGH ACCELERATION FOR MOTOR NO.18
ION TO VELOCITY 150 ON MOTOR-CURVE
T-LOSS DURING ACCELERATION=5.06%
TRIBUTION =1.77%
ISE OF TEMPERATURE OF 75°C.
ENERGY INPUT
INITIAL ACCELERATION
MOTOR CAPACITY
Y X LENGTH OF RUN IN MILES½ = H.P. PER TON
20
10
2
A
3
4

CS 4 gives the horse-power per ton for the same conditions; in the first paper, motor-capacity was given in kilowatt input; here it is reduced to horse-power output. These curves give the motor-capacity per ton required for any run expressed in terms of the maximum power input at the end of the initial acceleration.

An example will best explain their use. Suppose,

Schedule speed = 30 mph.
Distance = 7000 feet.
Time of stop = 25 sec.

Then

Time from start to start = 159 sec.
" " " " stop $- T =$ 134 ";
Average velocity = 30×159/134 = 35.6 mph
Through acceleration, A = 35.6/134 = .266

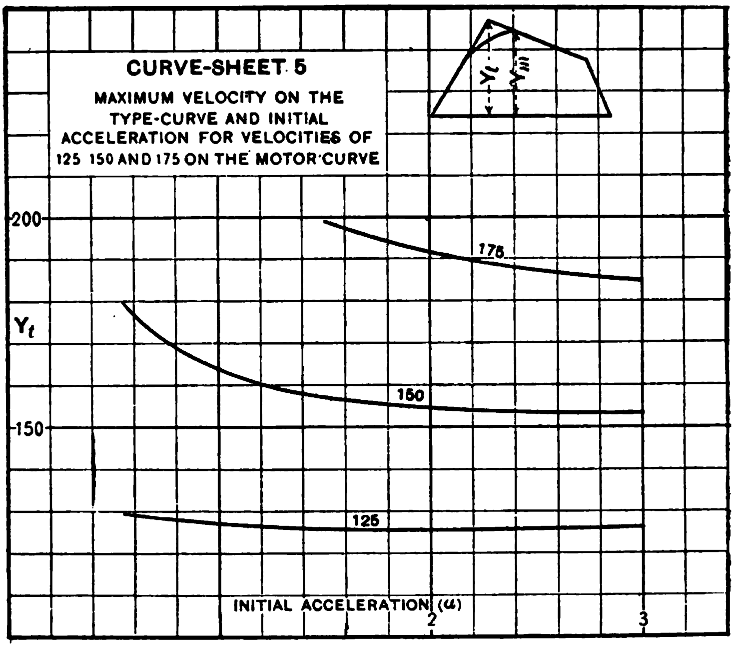
Suppose further that the speed, energy and motor-capacity are to be determined for

$(a) = 1.25$ mph/sec.,

and a velocity on the motor-curve of 150.

Then,

Relative maximum velocity on type-curve = 160 (CS 5).



(CS 5 is plotted from the velocity-time curves for the various initial accelerations.)

$x/T = .306$ (CS 1)

Hence,

$ax/T = .306 \times 1.25 = .382$

and

$ax = .382 \times 134 = 51.2$ mph.

This is the maximum velocity on the type-curve.

Hence,

Maximum velocity on motor-curve $= 150/160 \times 51.2 = 48$ mph

and

Velocity at resistance out $= 100/150 \times 48 = 32$ mph

hence,

Velocity coefficient $= .32$

(Velocities are uniformly expressed in terms of the velocity at maximum power, as 100; the actual velocities are then equal to β 100, where β is a coefficient determined as indicated here, or in the manner explained in the first paper.)

Time of initial acceleration $= 32/1.25 = 25.6$ sec.

Usually it will not be necessary to determine the times required by the various parts of the run, but this can be done as follows:

$x/T = .306$ (CS 1)

$y/T = .545$ (CS 1)

$z/T = .149$ (CS 1)

1.0000

Hence

$x/T = 41$ sec.

$y/T = 73$ "

$z/T = 20$ "

$T = 134$ sec.

Referring to Fig. 2:

Time of initial acceleration................(OP) = 25.6 sec.

Time of acceleration on motor-curve........(PR)

$= \beta \times 112 = .32 \times 112$, (CS 6).. = 35.8 "

(CS 6 is taken from the separate velocity-time curves.)

Time of total acceleration..................(OR) = 61.4 sec.

Time of total acceleration on type-run.......(OD) = 41 "

Difference..............................(DR) = 20.4 sec.

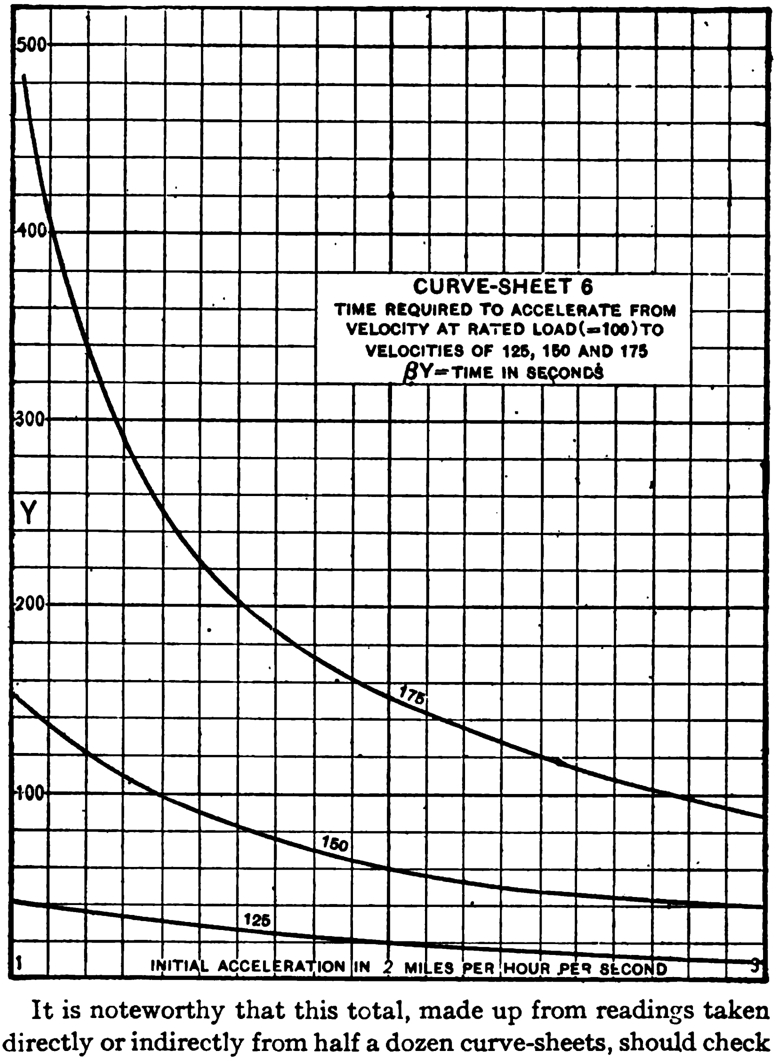
Time coasting on type-run.................(DE) = 73. "

Difference, time coasting on motor-run......(RE) = 52.6 sec.

The various times are then,

Initial acceleration........................(OP) = 25.6 sec.
Motor acceleration..........................(PR) = 35.8 "
Coasting....................................(RE) = 52.6 "
Braking.....................................(EC) = 20. "

Total.......................................(OC) = 134.0 "



CURVE-SHEET 6
TIME REQUIRED TO ACCELERATE FROM VELOCITY AT RATED LOAD(=100)TO VELOCITIES OF 125, 150 AND 175
βY=TIME IN SECONDS

It is noteworthy that this total, made up from readings taken directly or indirectly from half a dozen curve-sheets, should check exactly; of course such accuracy is partly accidental, but it shows how well graphical work of this character can be done.

The distances passed over for the various portions of the run can be calculated in a similar manner from other curve-sheets, which are not given here.

Further, from CS 4.

$$\text{Motor-Capacity} = 10.8\left(\frac{7000}{5280}\right)^{\frac{1}{2}} = 12.5\ \text{hp/ton.}$$

Energy per ton-mile = 92 wh. (CS 3).

The results of the assumption of any other initial acceleration are obtained in the same manner.

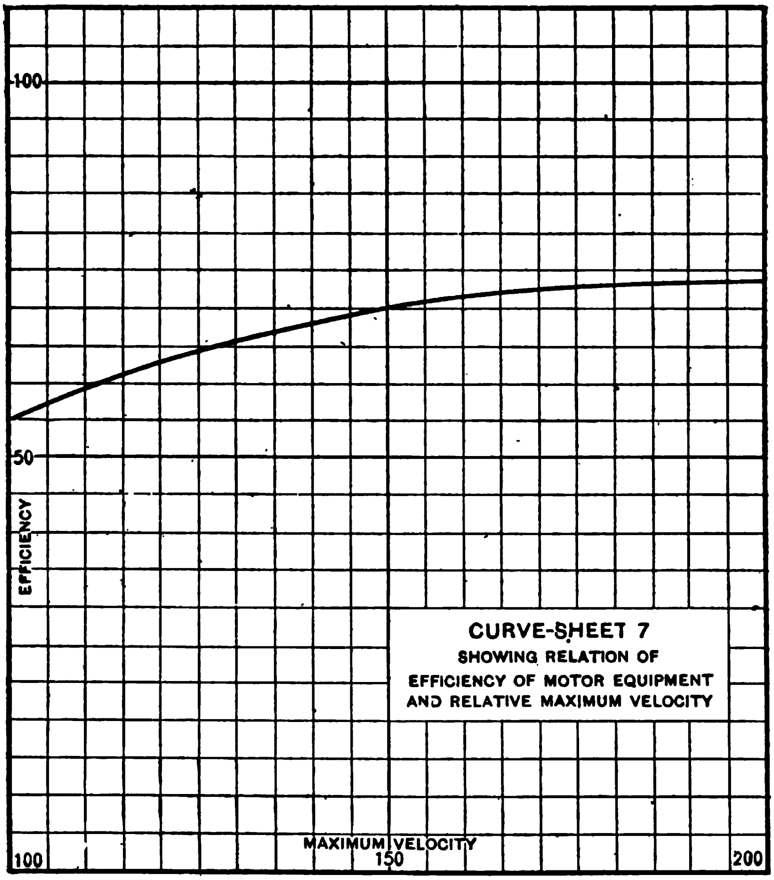
These calculations show that the energy consumption and motor-capacity can be determined when the " through acceleration," the initial acceleration and the amount of use of the motor-curve are given. As I show below, the initial and motor accelerations are fixed by considerations of heating; hence the conditions are entirely determinate.

The input and output of the motor when accelerating to any maximum velocity at any rate can both be obtained by integrating the appropriate power and velocity curves. A comparison of these figures shows that the efficiency for constant maximum velocity is practically independent of the initial acceleration. Both the input and output vary, but their ratio varies slightly; for instance, for a maximum velocity of 125, the input of the motor varies from 804 to 653 wh. when the initial acceleration is varied from .6 to 3.0 mph/sec.; for the same range the output varies from 517 to 415; hence the efficiency varies only from 64.3 to 63.5 per cent., a total variation of only .8 per cent. for a variation from .6 to 3.0 mph/sec. in the initial acceleration. Sixty-four per cent. may be considered the efficiency for a maximum velocity of 125, regardless of the initial acceleration. This is for the motor shown on CS 2, of which the efficiency at rated load is 85 per cent. For a maximum velocity of 175, the efficiency varies from 71 to 73 per cent.

CS 7 gives the efficiency of this motor equipment in terms of the maximum velocity. The values of efficiency from this curve-sheet can be used with small error to determine the input from the output.

A deduction from the fact that the efficiency is independent of the initial acceleration is that the average heat-loss is independent of the initial acceleration, which is also deduced directly. It is true that in the losses, friction loss is included, but the average friction-loss from zero to a fixed maximum velocity will not vary with the initial acceleration; hence the difference, representing the heat-loss, must be constant to the same degree of approximation that the efficiency is constant.

The formula following gives the work done at the car-axle per ton-mile for various schedules, in terms of the through-acceleration and the proportional part of the total time used in braking. This formula and the efficiency from CS 7 permit the easy determination of the energy-input per ton-mile.



CURVE-SHEET 7
SHOWING RELATION OF
EFFICIENCY OF MOTOR EQUIPMENT
AND RELATIVE MAXIMUM VELOCITY

The formula for work per ton at the car-axle is deduced by calculating the work of friction for the entire distance, and the kinetic energy at braking; by the substitution of

$$L = .682\, AT^2$$

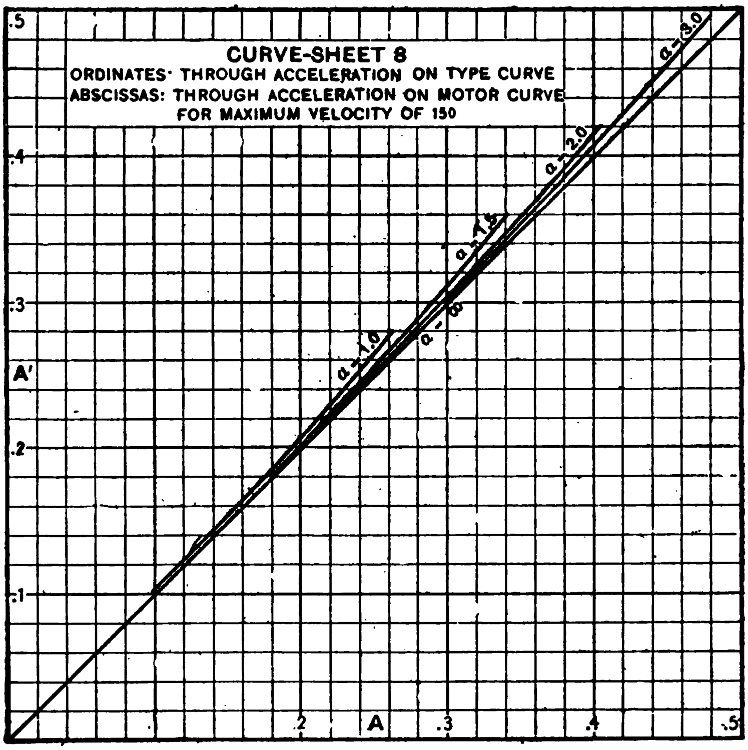
the through-acceleration is included, and hence the schedule. The formula is:

Work per ton-mile at car-axle $= 180\,b + 90\left(c - b\right)\frac{c}{A}\left(\frac{z}{T}\right)$ wh.

The first term, 180 *b*, gives the work of friction per ton-mile; the other term, the energy wasted in brakes per ton-mile. z/T is a function of the three accelerations, (*a*), (*b*) and (*c*), as well as of the through-acceleration. Hence the values of z/T to be used in this formula must be obtained from curve-sheets plotted for the particular values of (*b*) and (*c*) that are substituted in the formula. CS 1 is calculated for $(b) = .15$ and $(c) = 2$; substituting these values in the above formula, it becomes,

$$\text{Work} = 27 + 333/A \times \left(\frac{z}{T}\right)^2 \text{ wh.}$$

To apply this formula, find first the value of the through-acceleration on the type-curve corresponding to the through-acceleration *A* on the motor-curve, given by the data of the problem. CS 8 gives this relation for a maximum velocity of 150. Having this value of A^1, the through-acceleration on the



type-curve, select from CS 1 the value of z/T corresponding to that value of A^1 and of the initial acceleration in question. For example,

$$\text{For } A = .266$$
$$\text{and velocity} = 150$$

CS 8 shows that A^1 equals .275. The value of z/T for this value of A^1 and for an acceleration of 1.5 mph/sec., from CS 1 is .15, substituting in the above formula the work per ton-mile at the car-axle is found to be equal to 56 wh.; the efficiency, from CS 7 to 70 per cent.; hence the energy-input is 80 wh. CS 3 shows for the same conditions; *i.e.*, for $A = .266$ and $(a) = 1.5$, and energy-input equal to 83 wh., an agreement sufficiently close.

In the first paper, I assumed that an electric tramway motor in service will carry, on an average, a heat loss of 3 per cent. of its " hour-load," with a temperature elevation of 75° C. This is a fair average figure, but individual motors differ greatly in their heating characteristics; hence I have elaborated the method so that it may be used for motors having any copper-loss and any core-loss, for any schedule with any initial acceleration.

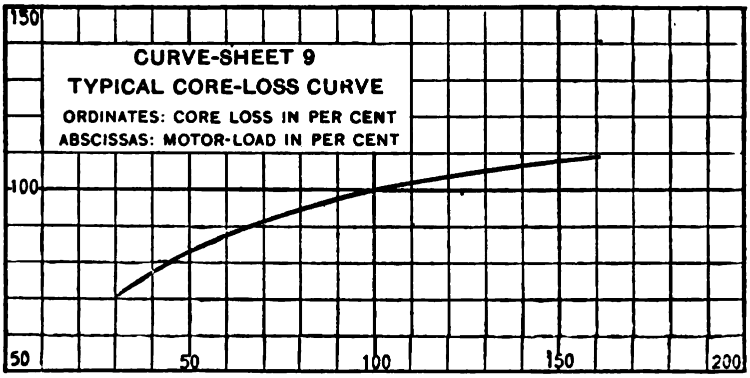
For this purpose I determine the ratio of average loss to loss at rated load for the copper-loss and core-loss separately, and for the several initial accelerations; knowing then the ratio of average loss during acceleration to loss at rated load, the average loss for any particular motor is found by multiplying the proper value of this ratio by the loss at rated load, separately for copper- and core-loss; the results added will give the total average loss during acceleration. These ratios of average to maximum loss were determined for velocities of 125, 150 and 175 on the motor-curve; that is, for maximum velocities 25, 50 and 75 per cent. greater than the velocity with resistance out. In describing this method further, it is to be understood that this procedure was followed in all cases; in other words, three separate sets of curves were carried through for the three maximum velocities, for the heat losses, for ratio of distribution, for motor-capacity, for energy-curves, and for the various other intermediate curves which were used as steps to the final results.

The rise of temperature of the parts of a motor, as determined by tests, depends upon the ratio of the distribution of the total heat-loss between the armature and field; to apply such test results correctly this ratio must then be known for the various conditions; hence the ratio of distribution was calculated for the several initial accelerations and maximum velocities; the average loss during acceleration and its distribution having been determined in this manner, the average loss during the run will be known when the ratio of time of acceleration to time of run, for the various initial accelerations, maximum velocities and for all values of the through acceleration is known.

Having then the average loss during the run and its distribution between armature and field, the rise of temperature of a motor, used under the conditions of service fixed by any particular ratio of distribution, can be determined by comparing this calculated average loss with the rise of temperature per watt lost, for the same ratio of distribution, as determined by tests in service.

These steps required the preparation of nearly a hundred curve-sheets and some four hundred curves; the matter is too voluminous to present here in detail; I shall therefore give only the results and call attention to a few of the principal stops.

The ratio of average to maximum copper-loss is definite and was determined in the usual manner by plotting values for the current and integrating.



The ratio of average to maximum core-loss depends on the variation of core-loss with speed and current; to fix this variation, the individual core-loss curves of a number of motors were plotted, and a curve determined showing the average variation of the core-loss. CS 9 shows the curve of the average variation of core-loss used in this investigation; the values from this curve were plotted on the various velocity-time sheets and integrated; this gives the core-loss during acceleration on the motor curve. In addition to this, core-loss curves of several motors, differing widely, were selected, and the ratios of average to maximum for different operating conditions were determined. These ratios were found to differ comparatively little for the different curves, much less than the actual values of the core-losses differ The average core-loss during the period of acceleration on resistance was taken at 42 per cent. of the maximum core-loss. This value was obtained from a number of separate core-loss curves.

The average percentage heat-loss during acceleration to the same maximum velocity for any motor is practically independent of the initial acceleration; the ratio of average to maximum copper-loss increases with the acceleration, while the ratio for the core-loss decreases.

The variation of the loss with initial acceleration in two typical cases is given in the tables following:

TABLE I.

Average heat-loss, for velocity of 150.
Copper loss at rated load = 3%
Core " " " " = 3%

Initial Acceleration.	Average Loss.
1 mph/sec.	3.88%
1.5 "	3.91
2. "	3.91
2.5 "	3.91

TABLE II.

Average heat loss, for velocity of 150.
Copper loss at rated load, = 7%
Core " " " " = 1%

Initial Acceleration.	Average Loss.
1.0 mph/sec.	4.77%
1.5 "	4.92
2.0 "	5.00
2.5 "	5.03

For velocities greater than 150, the variation is greater; for lower velocities it is less. The values for $(a) = 1.5$ are used.

Although this approximation is satisfactory for the purpose, yet if greater accuracy is desired, it is possible to plot the average loss for the various initial accelerations separately; but the complication is very much increased.

CS 10 gives the average percentage heat loss during acceleration for any combination of copper- and core-losses within the range covered, for a velocity of 150 on the motor-curve. The ordinates are average loss, the abscissas core-loss, and the inclined lines copper-loss; for instance, for a 4.0 per cent. copper loss and 2.5 per cent. core-loss, the intersection of the vertical at 2.5 with the inclined line marked 4, gives the average, loss of 4.12 per cent., and this will be the average loss occurring in a motor accelerating by series parallel, and then on the motor-curve to a velocity 50 per cent. greater than the velocity when resistance is cut out, the motor having a 4 per cent. copper- and 2.5 per cent. core-loss; the capacity being determined by the product of the torque during initial acceleration and the velocity with resistance out, that is the maximum power input.

The ratio of distribution is practically independent of the initial acceleration for a given maximum velocity, and for the range of initial accelerations used, *i.e.*, from $(a) = 1$ to $(a) = 3$. While this is not strictly correct, yet the difference between the values calculated accurately and the values found by assuming an average ratio of mean to maximum copper and mean to maximum core-loss, does not exceed 5 per cent. for the range covered; since this ratio is used only to fix the appropriate value of the radiation-constant (of which the determination is in itself necessarily rough) the degree of accuracy is sufficient.

CS 11 gives, for a velocity of 150, the ratio of distribution as ordinates, with core-loss as abscissas, and with inclined lines for the various copper losses; for instance, with copper-loss of 4.0 per cent. and core-loss of 2.5 per cent., the ratio of distribution is 2.44. It is assumed that the copper-loss is half in armature and half in field.

These curves then determine the average loss during acceleration and its distribution; to get the average loss during the run the ratio of time of acceleration to time of run must be known.

Referring to Fig. 3,

$$RH/OR = AD/OD$$

i.e.,

$$(100 + a\,t_2)/Y_t = (t_1 + t_2)/x$$

and

$$(100 + a\,t_2)/Y_t \times x/T = (t_1 + t_2)/T$$

$$= \text{Time of acceleration divided by total time.}$$

x/T is taken from CS 1 for the various values of A and (a), thus the ratio of the times is determined for all conditions; the corrections to the type-curve must be allowed for.

CS 12 has been prepared in this way; it gives the average percentage loss during the run, for various initial and through-accelerations, for a motor having a copper-loss of 4.0 per cent., a core-loss of 2.5 per cent., and consequently an average loss during acceleration to a velocity of 150, of 4.12 per cent. The ordinates are average losses in percentage of maximum input; the abscissas are through-accelerations and the separate curves are for the different initial accelerations.

The average loss during any particular run is equal to the average loss during acceleration multiplied by the ratio of the times, and since this ratio is independent of the losses in the motor, it is obvious that CS 12 will represent the average loss during that run for any motor, if the ordinates are varied in proportion to the average losses during acceleration. CS 10 gives the average losses during acceleration; hence these two sheets will determine the average losses for any motor for any run, accelerating to a velocity of 150 on the motor-curve. For example, a motor with a 9 per cent. copper and 2 per cent. core-loss has an average loss during acceleration of 6.7 per cent; curve-sheet 12 is plotted for an average loss of 4.12 per cent., hence if its ordinates be multiplied by 6.7/4.12 = 1.63, it will give average loss for the second motor.

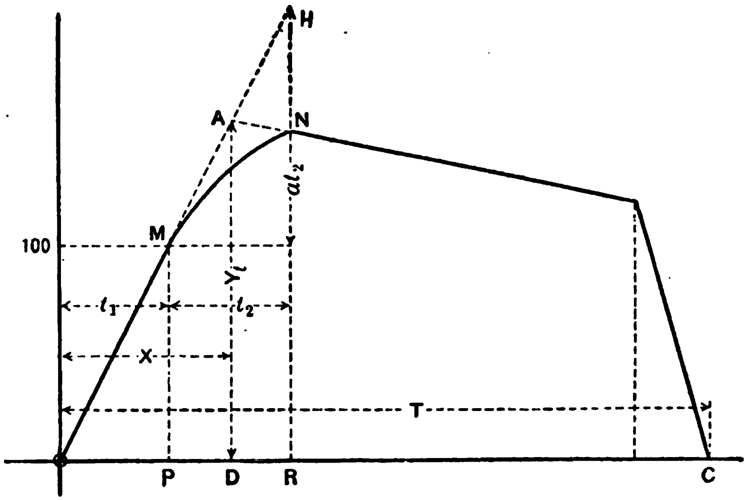


FIG. 3

For example,

For (a) = 1.25 mph/sec.
and A = .2 "
Average loss = 1.48% (CS 12)

and therefore

1.63 × 1.48% = 2.41%

is the average lcss or the second motor for the same run. Similarly for other combinations of copper- and core-loss.

These curve-sheets determine the average heat-loss of any motor for any run, and its ratio of distribution; it remains then to connect these calculated values with results of test made under comparable conditions of service, giving the temperature rise for various losses, *i.e.*, with the radiation coefficient of the motor under consideration.

Many tests of this nature have been made by the General Electric Company on its experimental track at Schenectady, by running trains back and forth over the track until permanent conditions of temperature have been attained, and at the same time, measuring the lcsses in the motors.

CS 13 gives such test results for a motor in general use; the ordiantes give the average loss in percentage of input that the motor will carry with a rise of temperature of 75° C. measured by resistance under the conditions of service determined by the ratios of distribution denoted by the abscissas; these curves are calculated from test results which give the rise of temperature per watt lost for field and armature separately; the curves are given for tests made with covers on the motors and covers removed. Thus CS 13 shows that for a ratio of distribution of 2, the armature of motor No. 13 will carry, with covers off, a load giving a lcss of 4.82 per cent., whereas the fields will stand only 3.1 per cent.; but if this motor be used with covers on, then at the same ratio the armature will stand a load giving a 2.05 per cent., and the fields at 1.88 per cent. loss, very nearly the same, as should be.

These test results are used as follows:

Motor No, 13 has

Copper-loss = 6.05%
Core- " = 2.10%

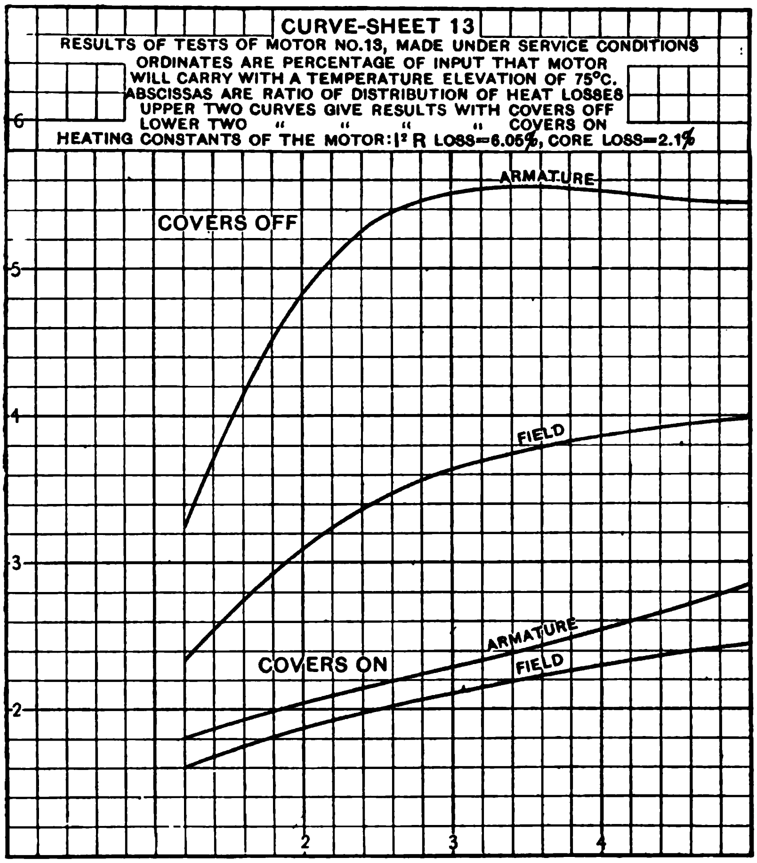
Then

Average loss during acceleration
to velocity 150 = 5.06% (CS 10)
Ratio of distribution of losses = 1.77 (CS 11)

At this ratio of distribution, the permissible loss, with covers on, is

Armature, 1.98% (CS 13)
Field, 1.80% (CS 13)

Hence the field controls, and the motor can carry only a load giving a loss of 1.8 per cent.; the armature will then run much cooler than 75°; in fact, at 1.8/1.98 × 75° = 68° C.



CS 12 is plotted for an average loss of 4.12 per cent., hence to apply it to motor No. 13, the ordinates should be increased in the ratio of 5.06/4.12 = 1.23: if this were done and a horizontal section of CS 12 were taken with the 1.8 per cent. line for ordinate, the initial accelerations would be determiend, for each through-acceleration, that would result in a loss of just 1.8 per cent. and consequently in the exact temperature rise permitted;

but the same numerical results will be obtained by taking a cross-section of CS 9 at the ordinate 1.8%/1.23 = 1.46%.

The dotted line marked "Motor No. 13" shows this cross-section. If the results of measurement by resistance, with covers off, be taken, the permissible loss for the field is 2.9 per cent., by CS 13; for this condition the cross-section line should be drawn on CS 12 at 2.9/1.33 = 1.35 per cent.

The values of (*a*), the initial acceleration for measurements by resistance with covers off, as determined by the cross-section line at 2.35 per cent. (not shown on CS 12), are plotted on CS 14 in terms of *A* as abscissa; the corresponding values of energy per ton-mile and of horse-power per ton for velocity of 150 are taken from CS 3 and 4. Thus, CS 14 gives the data for this motor under any conditions of service, for a maximum velocity of 150. The comparison has been made on the tacit assumption that the test results of CS 13 represent average losses during running time; if, as is usual, the test values represent average losses during total elapsed time, they must be increased in the ratio of total elapsed time to running time and this increased value used for the cross-section of CS 12.

This is all for a rise of temperature of 75° C.; if the permissible rise be 60°, then the permissible loss will be only

$$60/75 \times 1.8\% = 1.44\%,$$

and 12 must be cross-sectioned at

$$1.44/1.23 = 1.17\%,$$

to determine the proper accelerations for the various through-accelerations.

CS 12 then gives the rise of temperature of any motor for any through acceleration, with any initial acceleration, after its cross-section line has once been fixed; for example, for this motor the 75° rise is given by the accelerations having for ordinates 1.46 per cent.; suppose that for the through-acceleration $A = .2$, an initial acceleration of 1.0 be used; then the average loss will be 1.93 per cent., and since temperatures are proportional to losses, the temperature of the hottest part will be $1.93/1.46 \times 75° = 99°$ C. If an initial acceleration of 1.75 mph/sec. be used, the rise of temperature will be $1.00/1.46 \times 75° = 51°$ C.

That is, for any motor and any value of *A*, the ordinates of CS 12 will give the rise of temperature for any initial acceleration; each initial acceleration corresponds to a definite rise of temperature for each through-acceleration; a vertical cross-section of CS 12 at any value of *A* shows the relation of rise of temperature and initial acceleration for that through-acceleration. The dotted vertical line on CS 12 gives the temperature scale for motor No. 13, for $A = .25$ and $(a) = 1$, the rise will be 134°; for $A = .15$ and $(a) = 2$, the rise will be 40.5°. The temperature scale can thus be drawn on CS 12 for any motor, knowing its heating constants.

In order to avoid confusion, it is essential to recall that each change of initial acceleration means a proportional change in motor-capacity, the motor-capacity being directly proportional to the product of initial torque and the rated velocity. It is thus tacitly assumed that the engineer has a complete range of motors of all capacities, all with the same heating constants; but the results are given in horse-power per ton and hence they give merely a determination of the load that any given motor will carry, under the various conditions.

Returning to the example given on page 6, where the initial acceleration was assumed to be 1.25 mph/sec.; if the heating constants of the motor to be used are known, the initial acceleration will be fixed; assume the motor for this run to have these constants:

$$I^2R\text{-loss} = 3.6\ \%$$
$$\text{Core-loss} = 2.75\%$$

Then

Ratio of distribution = 2.8 (CS 11)
Average loss during acceleration = 4.06% (CS 10)

Assume,

$$\text{Radiation at ratio of } 2.8 = 1.6\%$$

Then a horizontal section of CS 12 having as ordinate

$$4.12/4.06 \times 1.6\% = 1.62\% \text{ gives,}$$

for $A = .266$ — the through acceleration under consideration, —

$$\text{Initial acceleration} = 1.5 \text{ mph/sec.}$$

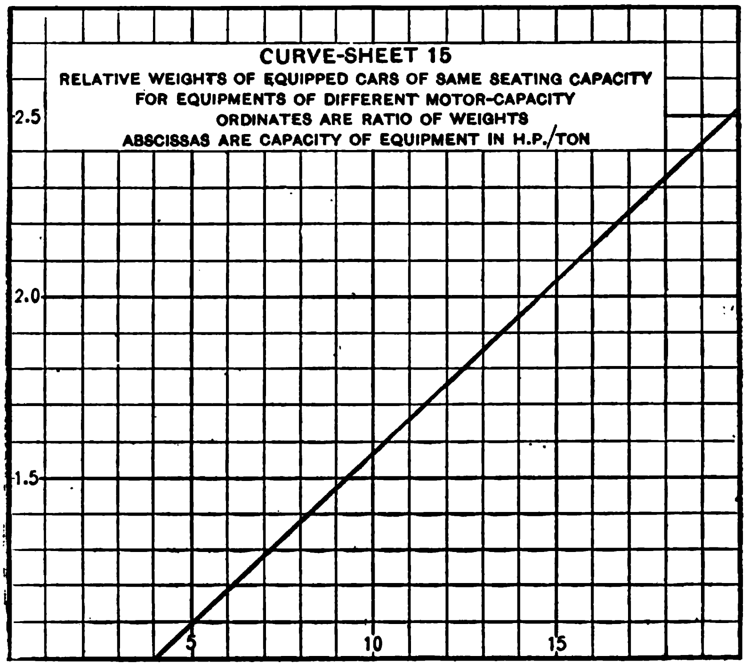
and

$$\text{Energy} = 83 \text{ wh} \qquad \text{(CS 3)}$$

$$\text{Capacity} = 1.16 \left(\frac{7000}{5280}\right)^{\frac{1}{2}} = 13.3 \text{ hp/ton.} \qquad \text{(CS 4)}$$

This example corresponds to an actual case; the engineers of the project have decided to use an initial acceleration of 1.5 mph/sec., and expect to obtain an energy consumption of 87 wh. per ton-mile; these figures agree closely with those above.

CS 14 gives what may be called the "characteristic performance" of Motor No. 13, used for any schedule as determined by resistance measurements with covers off. It is obvious that curve-sheets similar to this can readily be plotted for maximum velocities of 125 and 175. A comparison of such curve sheets for the different maximum velocities will, in general, show slight variations in motor-capacity for different initial accelerations, for a given schedule. In some cases the minimum motor-capacity is attained with an average maximum velocity, say, from 140 to 150; in other cases the motor-capacity diminishes as the maximum velocity is increased, up to the limit used in this investigation. No general conclusions can be drawn for the particular relative maximum velocity to be used; this depends principally upon the heating constants of the motor, including the radiation. It is clear, however, that by the aid of curves such as CS 12 for the various maximum velocities, the minimum motor-capacity can be found for any particular motor; all that is necessary is to draw the cross-section lines at the proper points, thus fixing the value of the initial acceleration, and then to select the values of energy and horsepower from the different curve-sheets. In the case of Motor No. 13, CS 14 for velocity of 150 gives practically the minimum motor-capacity; there is a diminution for greater maximum velocities, but it is comparatively unimportant.



CURVE-SHEET 15
RELATIVE WEIGHTS OF EQUIPPED CARS OF SAME SEATING CAPACITY FOR EQUIPMENTS OF DIFFERENT MOTOR-CAPACITY
ORDINATES ARE RATIO OF WEIGHTS
ABSCISSAS ARE CAPACITY OF EQUIPMENT IN H.P./TON

In all cases, the particular initial acceleration leading to the minimum motor-capacity should be adopted, even though this initial acceleration does not give minimum energy. The curves give the energy required per ton of total weight; hence the energy required per car is proportional to these figures multiplied by the relative weight of the car. The difference in the energy per ton for any schedule, is comparatively slight for the different maximum velocities, and in all cases the energy required per car is a minimum for the minimum motor-capacity with which the schedule can be made; the increase in the weight of equipment much more than balancing the diminished energy per ton obtained by using higher initial acceleration and higher motor-capacity. CS 15 gives the ratio of weight of equipment of different capacities; it is substantially the same as CS 15 of the former paper. The energy per ton multiplied by the ordinates of this curve-sheet gives relative figures showing the energy per car.

By this method, the two quantities that have, up to this point, been matters of arbitrary choice, are determined, *i.e.*, the initial acceleration and the relative maximum velocity on the motor-curve. Having then a motor with known heating constants, all the conditions which should govern its use for any particular schedule are fixed, and consequently the difference in the results attained by the use of motors with different heating constants is also determined.

I have illustrated the application of this method in comparing the availability of motors with different heating constants for a particular service. It is clear that it can also be used to obtain the data for different schedules. As an example of this use, suppose the data for various schedule speeds for a run of 7,000 feet, with twenty-five second stops, are to be determined.

Assume the motor represented by CS 14; then Table III. will show the performance of this motor for the various schedule speeds. In this Table, columns 1, 2 and 3 are calculated from the length and time of stop; columns 4, 5 and 6 are taken from CS 14; column 7 gives the ratio of the numbers of column 6, taking 7.4 as 100; column 8 is taken from CS 15; column 9 gives the relative total energy required per car; it is obtained by dividing the product of the figures of columns 5 and 8 for each schedule speed, by the corresponding product for a schedule speed of 25 mph. As the weight ratios of CS 15 are for a motor-car of the same size, but with different motor equipments, the figures of column 9 give the relative energy requirements per car-seat or per passenger for the different schedule speeds. Column 7 of this table may be taken as a sort of rough indication of the relative cost of the equipment for the different schedule speeds, and column 9 of the relative operating costs. They illustrate forcibly the great increase required both in motor equipment and in energy consumption for comparatively small increases in schedule speed.

TABLE III.

Schedule Speed	Average Speed.	Through Acceleration.	Initial Acceleration.	Wh/Ton.	Hp/Ton.	Relative Motor-Capacity.	Relative Weights of Equipment.	Relative Total Energy.
1	2	3	4	5	6	7	8	9
25.	28.8	.174	.77	63	7.4	100	1.49	100
27.5	32.1	.216	.93	77	9.4	127	1.65	137
30.	35.6	.266	1.15	99	12.3	166	1.89	199
32.5	39.1	.320	1.42	127	15.9	215	2.37	320
35.	42.9	.386	1.84	180	24.0	324	2.92	580

The curve-sheets show initial accelerations as high as 3 mph/sec., and through-accelerations up to $A = .4$; these values are beyond the range of practice, both on account of the excessive motor-capacity demanded and the close approach to the slipping point of the wheels, with the usual percentage of total weight on drivers. The boundary lines of the curve-sheets can fairly be taken as

$$A = .1 \text{ to } A = .3$$

and

$$(a) = .8 \text{ to } (a) = 2.$$

This indicates the comparatively narrow limits within which all schedules are brought by the use of the quantity A.

It is obvious that the methods outlined here can be applied to alternating current motors by the use of appropriate speed-torque curves in place of those of CS 2.

The method which has been developed takes account of all the factors governing the rise of temperature of motors under conditions of service. While certain assumptions have of necessity been made—as, for instance, a constant value for train-friction—it is perfectly feasible to re-calculate the curve-sheets with other values of train-friction; a set of curve-sheets similar to CS 12, including as many maximum velocities as may seem desirable, can be prepared and used as standard curves from which the rise of temperature of any motor can be determined very simply, for any conditions of service.

While the results obtained by this method are of necessity an approximation because of the number of assumptions that it is necessary to make in developing the method, yet numerous applications of the curve-sheets to practical examples have shown that the approximation is close, and that the curves furnish a useful means for determining the performance of any motor in service.

Discussion.

President Arnold stated that he believed those present had been much interested in Dr. Hutchinson's paper as it supplemented the paper the author had previously delivered before the Institute; that some of the members, when solving railway problems, had found that some of the previous conclusions of the author were nearer correct than some who discussed the paper were willing to concede at the time it was read. That as the railway motor problem was becoming more important as the size of motors increased he was glad the author had seen fit to supplement his former paper with the present one and discuss more fully the relationship of heat upon the capacity of motors.

Mr. A. H. Armstrong:—The paper presented by Dr. Hutchinson is of such a broad scope that it requires careful study before intelligent discussion is possible, and my remarks are therefore limited to one or two aspects of the problem. The author has adopted a method, in common with others, of following through the performance of the motor in practice, segregating the losses, proportioning them between armature and field, getting their ratio and subsequently connecting these results with the temperature rise by means of the actual performance of the motor determined by a series of experimental tests. Various papers have been brought out on the subject, notably that of Mr. Mailloux, which very carefully considered a method of plotting speed-time curves, and while the paper of Dr. Hutchinson has not given much space to this detail it has attempted to bring out a broad method of arriving at the service capacity of railway motors. There are one or two points which the author has not touched upon, perhaps not considering them necessary in the rather broad manner in which the subject has been taken up. The first of these is the neglect to include in the speed time and ampere-time curves the effect of the energy lost in accelerating the rotating parts of the train. In slow-speed work, that is, where the maximum speeds do not much exceed 30 mph., the energy required to rotate the motor armature, gears, wheels, axle, etc., may amount to a possible 15 per cent. of the total accelerating energy required for the train. Problems similar to the operation of trains on the New York Elevated would come in this class. In suburban work where cars reach a maximum speed of 60 mph. or more, the energy demanded to accelerate the rotating parts will not be more than 4 or 5 per cent. of the energy input to the train during acceleration. As both of these percentages are given in terms of energy input during acceleration and do not consider total input for the completed run, it is evident that leaving them out would not introduce a very large error, but the inaccuracy would be greater at low speeds than at high speeds.

The paper is based upon the assumption of a constant friction-rate, the author assuming 13.6 lb. per ton for all speeds. As the problem is worked out for only this one friction-rate, the conclusions arrived at in the final curves cannot therefore in any way be assumed as general in their application, due to the fact that train-friction varies greatly with the speed, especially in single car operation. In fact, a friction-rate of 13.6 lb. per ton would not have a field of application outside of the Rapid Transit problems involving the use of four or five cars in a train and operating at speeds not greatly exceeding 30 mph. maximum. If the problem is to be treated in a broad way, it is necessary to assume a number of friction curves, agreeing with the number of cars in a train, their shape and the load which they carry, and determine motor-capacities for all these different friction-curves. It would be sufficient to plot motor-capacities on the basis of three friction-curves and interpolate for friction-values lying within their scope. This has not been done and it leads to some inaccuracy in some of the conclusions arrived at in the paper. For example, the paper is based upon maximum speeds reaching 25, 50 and 75 per cent. above the speeds at which starting resistances are cut out. Based upon an assumption of 13.6 lb. per ton it is possible to get these different maximum speeds, but from tests which the General Electric Company has made and which have been corroborated by other authorities, it has been found that the friction of single cars of light construction sometimes reaches 50 or 60 lb. per ton when operating at speeds of 60 mph. or more. One of the examples given in the paper mentions a maximum speed of 50 mph., so that the author evidently had in mind the universal application of his curves, an assumption which is obviously incorrect considering that they are all plotted for a constant friction of 13.6 lb. per ton.

It is interesting to note the maximum speeds which it is possible to reach with a given motor when operating trains of different composition, giving different friction-rates. For example, a single car operated at a maximum speed of 30 mph. with a motor of modern construction having a rational speed-torque curve makes it possible to reach a maximum speed which is double that at which starting resistance is cut out; in other words, expressed in the terms of the author's paper, it is possible to obtain a value of 200 under these conditions. For two cars operating at the same speed, it is possible to obtain a maximum speed of 226, while for a train of heavy cars it is possible to reach a maximum speed of 250. It would therefore be possible to obtain the maximum speeds of 125, 150 and 175 mentioned in the paper, provided the maximum speed of the train expressed in miles per hour did not greatly exceed 30. For the higher friction-rates obtaining in higher speed service, that is possibly as high as 75 mph., the maximum speeds mentioned by the author are not possible. For example, a single car operating at 75 mph. could hardly exceed a maximum speed of 123, assuming the speed at which starting resistances are cut out to be 100. Two such cars make it possible to reach a maximum speed of 140, and for a train of heavy cars giving lowest friction-rate obtainable a maximum speed of 190 could possibly be reached." If the conclusions are based upon a maximum speed of 150 and the paper carried through on this basis, the results would not apply to universal railway work, especially when high-speed problems are encountered. The results arrived at in the paper are applicable therefore more especially to rapid transit problems similar to the New York Elevated, but would not give accurate results for all classes of service.

On page 1570 the author gives a table showing the motor capacities required for certain runs under given conditions. Some results obtained from experimental tests of motors are at hand giving the energy-consumption, and it is very interesting to compare the results obtained by attacking the problem from different standpoints and by different investigators. The results obtained so far as they relate to the relative capacity of motor required check fairly well as the following table indicates. The figures given below relate to the column 5 on the table given on page 678, which details the watt-hours per ton-mile required for the conditions named. Column A is quoted from the table and Column B from experimental results.

A.	B.
63 wh.	50 wh.
77	60
99	73
127	102
180	125

Column 7 in the same table gives the relative motor capacity required for a temperature rise of 75° C. above the surrounding air. As in the previous table, column A is quoted from the table and column B from experimental results.

A	B
100	100
127	125
166	156
215	212
324	281

These figures also show a fair agreement. Comparing column 6 with experimental results, the same agreement does not hold as shown in the following table. This column is understood to give the horse-power rating of the motors based upon a stand test which will permit a rise of 75°C. above the air in the hottest part of the motor. Column A is quoted from the table and column B from experimental results.

A	B
7.4	5.5
9.4	6.9
12.3	9.3
15.9	11.5
24.	14.5

The figures quoted in the table of the paper seem to be some 50 per cent. greater than the value in column B obtained from experimental results.

These figures all contemplate a fixed friction-rate of 13.6 lb. per ton. It has been found that with the friction-rate obtained at speeds of 60 mph. or more, the motor-capacity demanded will increase fully 20 per cent. more than the values indicated by the flat friction-rate of the author's paper. This percentage increase will depend upon the composition of the train, whether a single car is operated alone or several cars are operated in a train. In other words, the high-speed problem must be treated upon the basis of several friction-curves plotted to meet the different operating conditions, using that curve for obtaining the motor-capacity and energy-consumption which applies to the case in hand. The energy-consumption at high speeds is very greatly affected by the rate of friction assumed. In slow-speed work, to which the paper as given must be confined owing to the assumption of 13.6 lb. per ton friction-rate, the energy demanded in accelerating the train is very considerable compared with that required to overcome friction, and hence the latter is of secondary importance as affecting the energy-consumption. At higher speeds, however, approaching 60 mph. or more, especially when single cars are operated at these speeds the friction-rate determines the energy-consumption, and the energy lost in accelerating becomes in turn of secondary importance. For example, with a friction-rate of 20 lb. per ton, which might be assumed for a train of several cars at 60 mph., the energy-consumption must necessarily be 40 watt-hours per ton-mile, or double the friction-rate, without introducing any energy-loss due to acceleration or heating of the motors.

On the other hand, a single car weighing 30 to 35 tons, operating at this same speed would have a friction-rate very close to 50 lb. per ton, demanding 100 watt-hours per ton-mile without any energy lost in accelerating the car or in the motor. This indicates the extreme importance of carefully determining by exhaustive tests what friction rate should form the basis of calculations for the case in hand, and a broad treatise on railway motor capacity will be of value only when applicable to any friction-rate at any speed.

MR. CARY T. HUTCHINSON:—Mr. Armstrong's remarks seem to require some explanation in order that this matter may be made clear. In general, Mr. Armstrong attempts to imply results from a particular example, illustrating a general method, to conditions under which they are clearly not applicable. It is distinctly stated that the paper is intended to develop a method of treating this problem; the numerical results given are merely illustrations; nevertheless, these numerical results should be in agreement with results obtained by other methods, *under identical conditions.*

Mr. Armstrong's first criticism is that a constant friction-rate of 13.6 lb. per ton has been taken, and that such a rate is entirely too low for high maximum-speeds. This is, of course, correct; it is stated in the paper that some constant rate must be assumed and that if problems are to be solved involving a rate differing greatly from the rate assumed, new curve-sheets must be drawn, based on the proper friction-rate. The effect of a different friction-rate upon the energy required is easily determined by the equation on page 666 of the paper, giving the work done. The constant 27, in this equation is equal to the watt-hours per ton-mile for a friction-rate of 13.6 lb. per ton; the second term of that equation gives the additional energy required for the various schedules. If any other friction-rate than 13.6 be used, the work of friction will be increased approximately in that ratio.

It is not intended to deny the very great importance of using the proper friction-rate, particularly for high-speeds; but only to point out that a criticism of the method based on this fact is not to the point, since in the paper itself the necessity for considering this fact is pointed out.

Mr. Armstrong seems to be of the impression that the results of the paper are based on accelerating to a maximum speed 50 per cent. greater than the speed at resistance-out. This of course is not the case. The paper states that curves were plotted for velocities of 125, 150 and 175, and that the minimum motor-capacity for any particular run is to be picked out from the results at these various velocities. It happens, however, that a maximum velocity of 150, in many of the cases examined, gave very nearly the minimum motor-capacity, hence curve-sheets for this particular value of the maximum velocity were presented, as illustrating average conditions better than any other value. The method, however, is applicable to any maximum velocity that it is possible to obtain with the train-friction assumed.

The next point referred to by Mr. Armstrong—*i.e.*, the possible maximum-velocity—is merely a question of the ratio of the train-friction to initial horizontal-effort, and therefore involves the initial acceleration used. With a train-friction of 13.6 lb. per ton, an initial acceleration of 1 mph/sec., and a motor so chosen that its rated torque will be approximately 105 lb., then after an infinite time the motor will come to a constant velocity, and the torque will be 13.6 ÷ 105 = 13 per cent. of the rated torque. A reference to the speed-torque curve of the motor, such as Curve-Sheet 2, will then immediately determine the maximum velocity. In this particular case, the maximum velocity would be about 200 per cent. with the velocity at resistance-out as 100. A similar calculation will give the maximum velocity for any friction-rate. The higher the friction-rate and the lower the initial torque, the lower will be the relative maximum velocity.

Mr. Armstrong's chief criticism is, however, that Table III. of the paper does not give results in close agreement with results obtained by his Company under practical conditions. Mr. Armstrong's figures give the horse-power rating of the motor based upon a rise of 75° C. above the air, in the hottest part of the motor, as measured by *thermometer*. The figures in the table, however, are for a rise of 75° C. determined by *resistance-measurements*, with covers off, and for a track test. To illustrate the effect of conditions under which the tests are made, the following table is given; it shows the per cent. of input that this motor will radiate for a temperature-rise of 75° C., under the service-conditions denoted by a ratio of distribution of 1.8, when measurements of temperature are made by resistance, by thermometer, and with covers-on the motors and covers-off. The energy and power per ton for a run of one mile, taken from CS 12 for a through acceleration $A = 0.266$ is added.

TEST RESULTS OF MOTOR 13 FOR RATIO OF 1.8.

No.	Temperature Measured by.	Covers of Motor.	Radiation for 75° C. in percent of input.
1	Thermometer	On	2.21%
2	Thermometer	Off	4.55%
3	Resistance	On	1.74%
4	Resistance	Off	2.78%

For $A = 0.266$ and a one-mile run

No.	Initial Acceleration (a.)	wh/ton.	hp/ton.
1	1.4 mph/sec.	85	11.4
2	Less than 0.8		
3	1.72	78	13.2
4	1.20	94	10.8

That is, with resistance-measurement the necessary motor-capacity is 22 per cent. greater with covers-on than with covers-off. This is the measure of the effect of ventilation. The curves are not continued far enough to give results for thermometer and covers-off.

The principal object of the paper was to show how to handle this problem for motors having any copper- and core-loss; Mr. Armstrong gives average results without any reference to the particular motor for which they were obtained, and consequently without any reference to the heating-constants of the motor. This is an added reason why no direct comparison of numerical results is possible.

A study of the paper will show that the results derived from the curve-sheets obtained in this general way must be accurate for the simple reason that they are based on the performance sheet of the motor itself, and introduce no possible errors other than those made in the assumptions given; the results will then be as accurate as are the experimental tests of the motor.

LOUIS DUNCAN (*by letter*):—The object of the paper seems to be the development of a systematic method for showing the effects of the different heat constants, *i.e.*, I^2R-loss, core-loss, and the radiation-constants upon the performance of railroad motors under service conditions. The I^2R-loss and core-loss may be obtained by shop-tests, while the radiation constants are determined by experimental track-tests under conditions imitating the problems to be solved. The author makes a number of assumptions in order to bring the probelm within the limits of general treatment. For instance, he assumes a straight, level track with constant train-friction and constant braking-force. As far as the constant train-friction goes this assumption would not hold within the limits of train velocities used in the paper, but it is near enough to give approximate results, and more accurate results could be obtained by plotting the different curves on the basis of a train-friction varying with the speed of the train. The author also assumes that the type of motor-curve is the same for the different motors whose performance he considers, and states that the shape of the curves for the different motors is practically the same, but that the efficiency varies through a considerably wider range.

In a number of the curves in the paper the different quantities are plotted in terms of a quantity "A," which the author calls " through acceleration." It should be constantly borne in mind in reading the paper that this quantity is deduced from the schedule speed and the length of run, these two quantities being introduced into the discussion by means of the quantity " A." Frankly, the writer does not consider that curves which show relations between real quantities, like acceleration, and fictitious quantities, like the quantity " A," are particularly instructive. Still, as a short method of arriving at the desired results, it has its uses. After plotting a number of curves giving the energy input in watt-hours per ton-mile and the motor-capacity per ton for different schedules, *i.e.*, for different values of " A," the author proceeds to introduce the heating-constants of the motors as determining their performance.

Curve-Sheet 10 in the paper connects the total percentage loss in the motor during acceleration with the percentage of I^2R-loss and the percentage core-loss, these all being in percentages of the maximum input of the motor. It is assumed in plotting these curves that the maximum velocity is 50 per cent. greater than the velocity when all the resistance is cut out. Using another set of curves which give the ratio of the time of acceleration to the total time for different schedules, Curve-Sheet 12 is prepared which gives the relation between the percentage total loss for the entire run, the schedule, and the initial acceleration—all of these quantities being for a motor which has an I^2R-loss of 4 per cent., a core-loss of 2.5 per cent., and an average loss during acceleration of 4.12 per cent., the maximum velocity being 50 per cent. higher than the velocity when all the resistance is cut out of the motor circuit.

This Curve-Sheet No. 12 may be used to determine the average loss during the given run for *any* motor, for while it is plotted for a motor having an average loss of 4.12 per cent. during acceleration yet if another motor had a loss of, say 5 per cent., it would only be necessary to multiply the ordinates in the ratio of 5/4.12. If the temperature attained by a particular motor under service conditions for any particular loss is determined by track-tests, it is clear that the initial acceleration leading to exactly this loss can be picked out for any schedule from Curve-Sheet 12. The author gives illustrations of the method of using this curve-sheet and establishing a temperature scale for motors having different losses than those of the motor for which the curve is plotted. In other words, Curve-Sheet 12 determines for any schedule, what initial acceleration must be used in order that a motor may have any desired temperature elevation, when the copper- and core-losses of the motor are known and the value of the radiation-constants of the motor are given by tests under service conditions.

From Curve-Sheet 12 the author obtains performance sheets such as Curve-Sheet 14, which gives the initial acceleration, the motor-capacity, and the energy-input for the particular motor considered in Curve-Sheet 12 for all schedules, the temperature rise being 75°. Similar curves could be prepared for different temperature rises. It should be noted that these curves are based on a maximum velocity 50 per cent. greater than the velocity with all the resistance cut out of the motor circuit, but the curves given in the paper would allow Curve-Sheet 14 to be varied to correspond with different maximum velocities. If curve-sheets are made for different maximum velocities and compared with one another, that maximum velocity for a given schedule may be selected which will give the minimum motor-capacity; *i.e.*, the maximum tons per horse-power capacity of the motor for which the required schedule can be made. The author states, and the writer considers this important, that the best results are always obtained with the minimum motor-capacity, for while the energy per ton-mile may not be a minimum, yet the difference is not great for any schedule for different maximum velocities, while the weight of equipment increases rapidly as the initial acceleration increases, so that the energy *per car* is less when the equipment has the minimum capacity necessary to make the schedule. This fact was brought out in the author's first paper and is further emphasized in this one.

What the author has done, then, is to develop a method for obtaining for a given schedule and a given rise of temperature, the capacity in h.p. per ton, the energy-input, and the initial acceleration for any motor, taking as data the I^2R- and core-losses of the motor and the radiation-coefficients determined by actual tests of the motor under service conditions. While he has made a number of assumptions, some of which are not strictly true, yet the applications of the method show sufficient agreement with the actual facts to prove that the method will be useful for practical purposes.

A paper presented at the 180th Meeting of the American Institute of Electrical Engineers New York, October 23, 1903.

A GRAPHIC RECORDING-AMMETER.

BY A. H. ARMSTRONG.

With the advance of the study of quick acceleration, the need was felt for an instrument capable of registering accurately current and voltage readings which fluctuate violently. Such an instrument must be capable of operating satisfactorily on a car moving at a high speed over bad track, and hence subject to vibration and shock. Sudden changes in the quantities measured required that the instrument should have a short period and should be perfectly damped. The swaying of the car, the rapid acceleration and retardation made it necessary that the instrument should be thoroughly balanced. In order to obtain a permanent record with freedom from sticking it was necessary to use ink, since even with the high torque of this instrument a metal stylus or graphite pencil-point would not give good-service.

To secure the required torque, a dynamometer construction is used, in which the current to be measured is carried by the fixed coil and a constant current of small value flows through the moving coil, supplied preferably by a storage-battery.

The moving coil, rectangular in shape, is composed of several turns of wire surrounding an iron core of cylindrical shape, and carries about one ampere; this coil and core are enclosed in the fixed coil. The moving coil is suspended by a controlling spring which holds it in position at the top, and is supported by a small steel shaft at the bottom; this bottom bearing is so made that when the instrument is in use the moving system hangs freely from the controlling spring, and the vertical motion is so limited that excessive vibration cannot take place. Current is led to the moving coil by two spiral conductors of negligible elasticity in comparison with the controlling spring; the controlling spring can be adjusted by changing its length.

The magnetomotive force in the fixed coil of an ammeter is about 2400 ampere-turns, and in the moving coil about 80 ampere-turns; with this combination, a torque of about 200 gramme-centimetres is obtained, which is from 80 to 200 times the torque of the ordinary measuring instrument in which the indications of a pointer on a scale are observed, and from 3 to 15 times the torque of the usual integrating, or curve-drawing instruments.

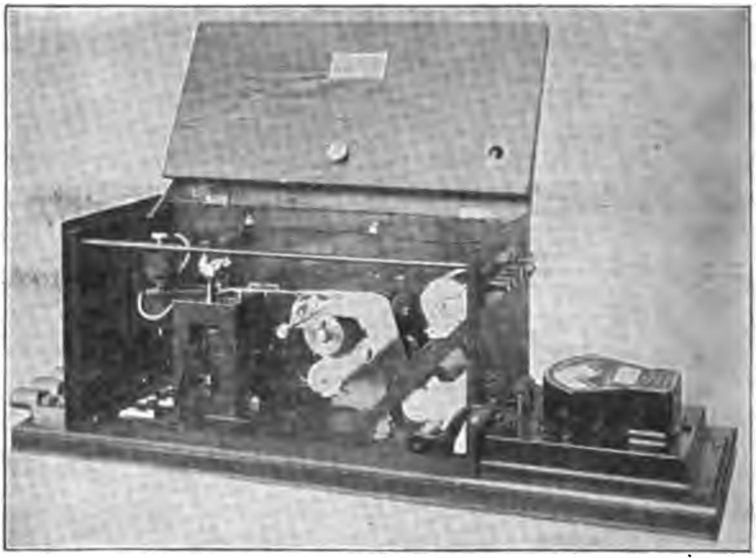


FIG. 1.

The pen used is a capillary tube supplied by a syphon which is filled from an ink reservoir placed at some distance from the recording point in the direction of the axis of the instrument. This arrangement secures a continual supply of ink and a fine line, and prevents blotting when the pen and paper are at rest. It also decreases the inertia of the moving system.

The different conditions under which the instrument is used require a variable pressure of the pen on the paper; if the instrument be used on a stationary platform, the pen should barely touch the paper if on a car moving at high speed, the entire weight of the pen should rest on the paper. This adjustment is made by means of a joint in the pointer and a small adjustable spring capable of supporting the entire weight of the movable part of the pointer.

The record is made on paper punched and ruled by a special machine and passed through the instrument by means of a toothed wheel driven by a spring motor, similar to that used for driving a phonograph. The speed of the paper can be adjusted to from four to eight inches per minute, but is ordinarily six inches per minute. The paper is about 3½ inches wide and is used in rolls 65 feet long. The machine that has been designed for ruling the paper can give any ruling, and special paper can be made for each instrument, ordinarily, however, instruments of the same capacity are nearly enough alike to permit paper of uniform spacing to be used.

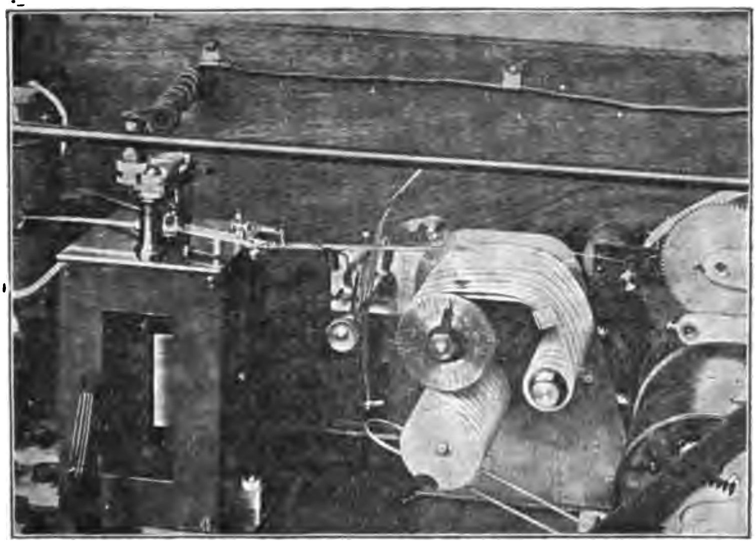


FIG. 2.

There is a second small pen employed to mark time accurately on the paper. This pen is actuated by a time-marker clock, through a small electromagnet, controlled by the clock. By this means, intervals of five seconds are marked on the paper. With this addition, it is possible to obtain simultaneous readings on a number of instruments placed upon different cars of a train. This marking device also serves to calibrate the speed at which the paper is moving, thus making it unnecessary to calibrate the paper by means of a watch.

This construction is, of course, applicable to a voltmeter or wattmeter, as well as to an ammeter. By the use of these instruments it is possible to obtain current and voltage readings with accuracy; the instrument does away with the labor of several men formerly required by the old method of two-second readings, and gives much more accurate results. It has become a simple matter to make all-day tests upon a railway motor, taking a sufficient number of readings to obtain a fair average, and thus determine the copper losses quickly and accurately. Knowing the voltage and current, it is possible to compute the core-loss of a motor from stand-tests and in this manner obtain the total energy-loss in heating the motor for any given service. The use of this instrument makes it comparatively simple in this way to determine the thermal capacity of a motor, and this with such accuracy that consistent results are assured in comparing motors of different sizes and designs.

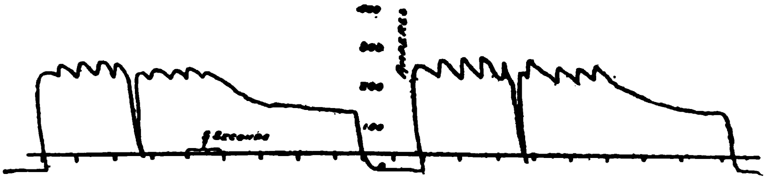


Fig. 3.—Current-curve taken by graphic recording-ammeter on a car equipped with multiple-unit control with automatic accelerating device.

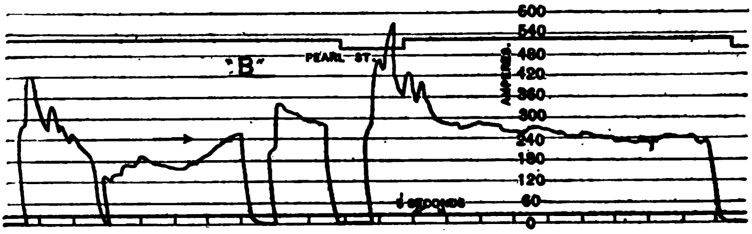


Fig. 4.—Current-curve taken by graphic recording-ammeter on one of the Schenectady-Albany cars equipped with four GE-73 motors. This car was climbing a heavy grade and the motors were in series.

Figs. 1 and 2 give general views of the instrument, and Figs. 3, 4, 5, 6 and 7 copies of records taken under different conditions.

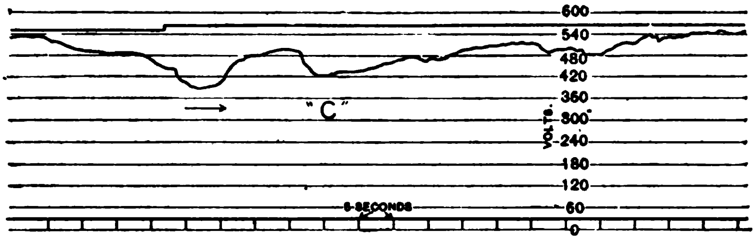


Fig. 5.—Voltage-curve taken by graphic recording-voltmeter on one of the Schenectady-Albany cars.

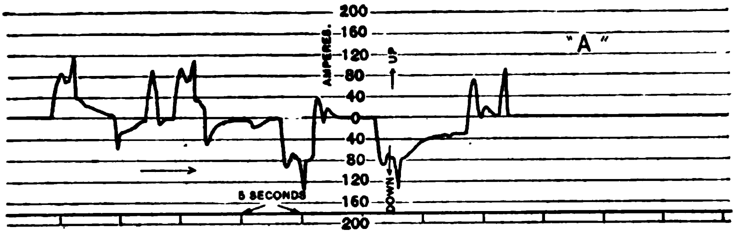


Fig. 6.—Current-curve taken by graphic recording-ammeter on an Otis elevator motor.

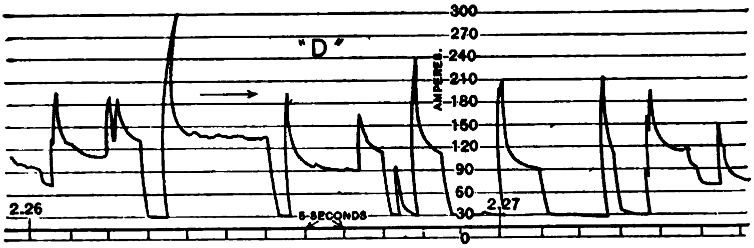


Fig. 7—Current-curve taken by graphic recording-ammeter on a compound-wound generator.

The general data of the instrument shown in Figs. 1 and 2 is as follows.

Length, 32½″
Width, 13½″
Height, 11¼″
Approximate weight, 100 lbs.
Torque of ammeter, 210 gm-cm. (Full scale 24 degrees.)
" " voltmeter, 200 "
Period, 0.33 seconds for complete cycle.

Ampere-turns in fixed coil of ammeter,	2400
“ “ “ “ “ voltmeter,	950
“ “ moving “ “ ammeter,	80
“ “ “ “ “ voltmeter,	189
Watts consumed in moving coil of ammeter,	1
“ “ “ “ “ “ voltmeter,.	3.3
“ “ “ fixed “ “ ammeter	130
“ “ “ “ “ “ voltmeter,	33

A paper presented at the 181st Meeting of the American Institute of Electrical Engineers, New York, Nov. 20, 1903.

THE ELECTRICAL CONDUCTIVITY OF COMMERCIAL COPPER.

BY LAWRENCE ADDICKS.

Electrical conductivity has come to be a universally accepted measure of the degree of purity of copper for two reasons· First, on account of the enormous quantities of copper used in electrical construction; Secondly, because the conductivity forms a very delicate test of the chemical purity of the metal. Furthermore, a conductivity test may be made upon a wire of suitable dimensions in about three minutes, while a chemical analysis of refined copper is a tedious and correspondingly expensive operation.

Matthiessen's standard (one metre-gramme of pure soft copper at 0° Centigrade = 0.14172 international ohms), has come into very general use, although it is some three percent too low. The fact that the quality of the copper on the market to-day often exceeds by as much as one percent the purest laboratory copper of forty years ago forms an interesting commentary on the excellence of modern methods.

Conductivity is affected by the physical state of a metal or alloy as well as by its chemical constitution. Now in order to obtain the sample of wire upon which a measurement is made, the copper under examination must be subjected to several mechanical processes, and these different variables must be taken into account. It is the purpose of this paper to point out their influence.

First, let us take up the influence of the chemical impurities commonly met with. These consist of oxygen in the form of suboxid of copper, arsenic, antimony, and, in some coppers, bismuth. Small quantities of some other elements, may be met with but those mentioned are the impurities to be looked for in low copper.

The relation between arsenic or antimony and conductivity is shown in Fig. 1. As arsenic and antimony have a very similar influence the data have been gathered as arsenic plus antimony, thereby greatly simplifying the work. The suboxid of copper is practically constant in all these determinations. The conductivity is stated for annealed samples of wire. It will be

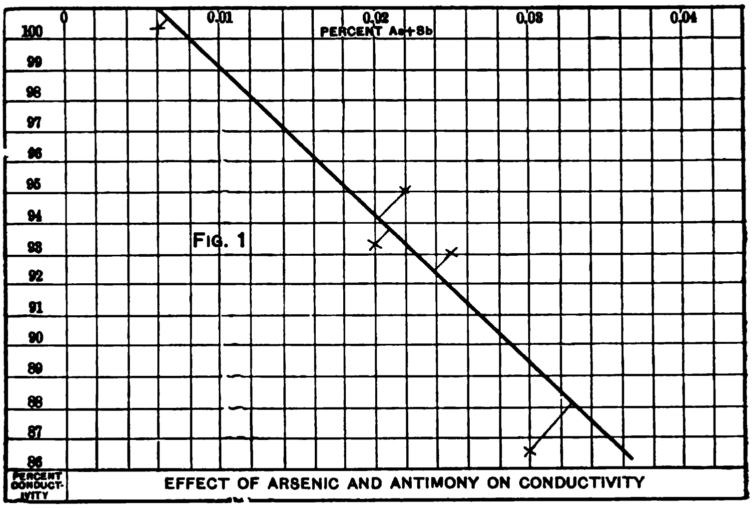


FIG. 1

EFFECT OF ARSENIC AND ANTIMONY ON CONDUCTIVITY

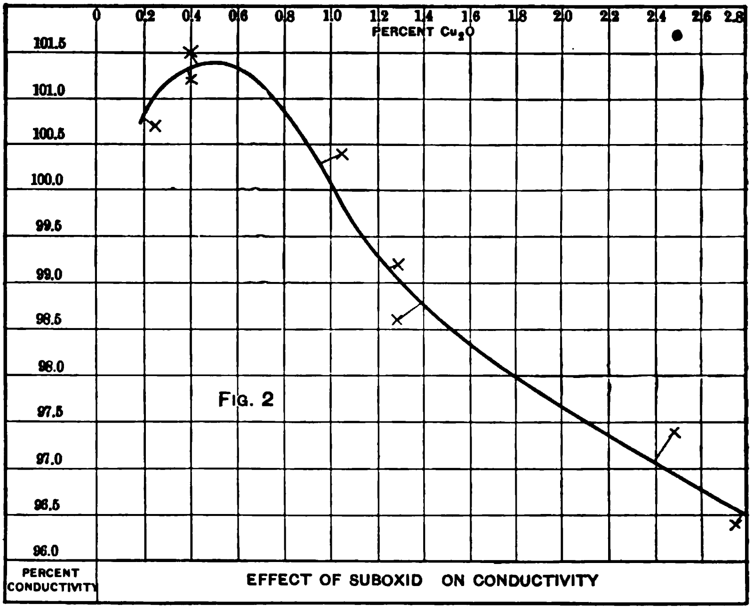


FIG. 2

EFFECT OF SUBOXID ON CONDUCTIVITY

noticed that 1/100 percent of arsenic or antimony lowers the conductivity about five percent.

Fig. 2 shows the relation between suboxid and conductivity in annealed wire. The suboxid has been calculated from the oxygen, itself obtained by subtracting the percent copper by analysis from 100. The quantity of other impurities present is so small that this is substantially correct. The crest of the curve shows copper " in pitch " or " set " or when sufficient oxygen is retained to keep the impurities as oxids, in which state they are supposed to be less harmful. The possible formation of a carbid or the absorption of hydrocarbon gases from " overpoling " in the refining furnace has also been suggested.

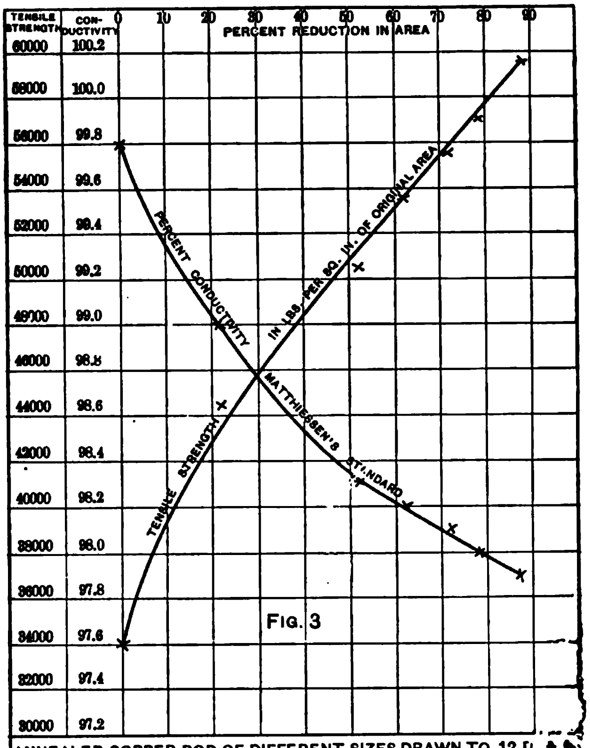


FIG. 3

ANNEALED COPPER ROD OF DIFFERENT SIZES DRAWN TO 12 B. & S.

We come now to the physical characteristics and their influence upon the conductivity. We can cause considerable changes in structure by mechanical operations and, as would be expected, the conductivity is affected thereby, but by no means as seriously as by arsenic or antimony. The operation most commonly met with is that of wire drawing—conductivity varies with hardness. In Fig. 3 conductivity and tensile strength are plotted against the percentage reduction in area of a wire rod after annealing and in Fig. 4 conductivity is plotted directly with tensile strength. It will be seen that the tensile strength varies almost directly as the reduction in area and that the conductivity drops about 1/10 percent for every 1,300 lb.

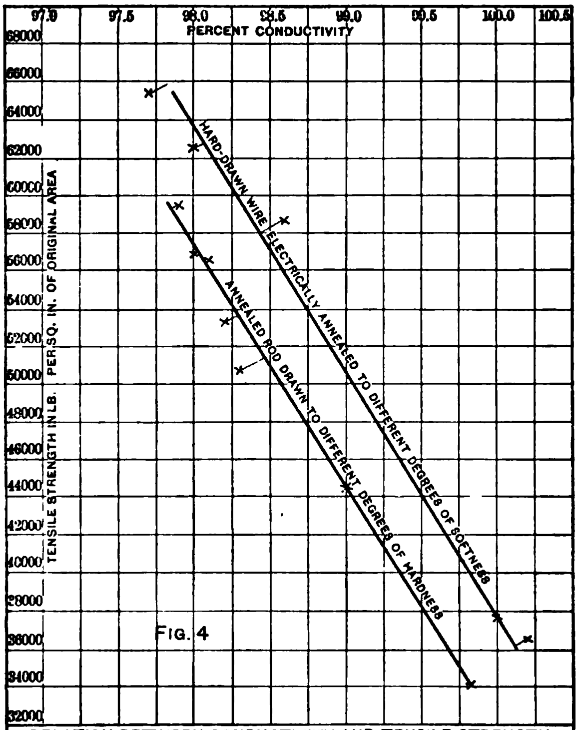


FIG. 4

RELATION BETWEEN CONDUCTIVITY AND TENSILE STRENGTH IN COPPER WIRE

gain in tensile strength, a fact which must be taken into account when comparing different samples of hard-drawn wire. Fig. 4 also shows results obtained where a hard-drawn wire is given different degrees of annealing. This ratio, shown by the angle of inclination of the straight line to the axes, is independent, in so far as the writer's investigations have extended, of the actual conductivity of the annealed wire, which is of course dependent upon chemical purity.

Fig. 5 shows the effect of temperature in the annealing operation. A hard-drawn, 12 B. & S., wire has been heated to various temperatures by being forced to carry currents from zero to a fusing current of about 220 amperes. The actual temperatures were not measured at the time the tests were made. Very roughly the temperature in degrees Fahrenheit will be about ten times the values shown for amperes. In the experiments quoted about ten feet of wire was put in series with a water rheostat and the whole shunted around forty or fifty volts of a 4,000-ampere circuit. The current was adjusted by acidifying the water in the rheostat and was left on in each case until it reached a steady value--a matter of about a minute. The time during which the current was on, after this steady heat was reached, seemed to exert no other effect than to increase the shell of scale formed on the wire.

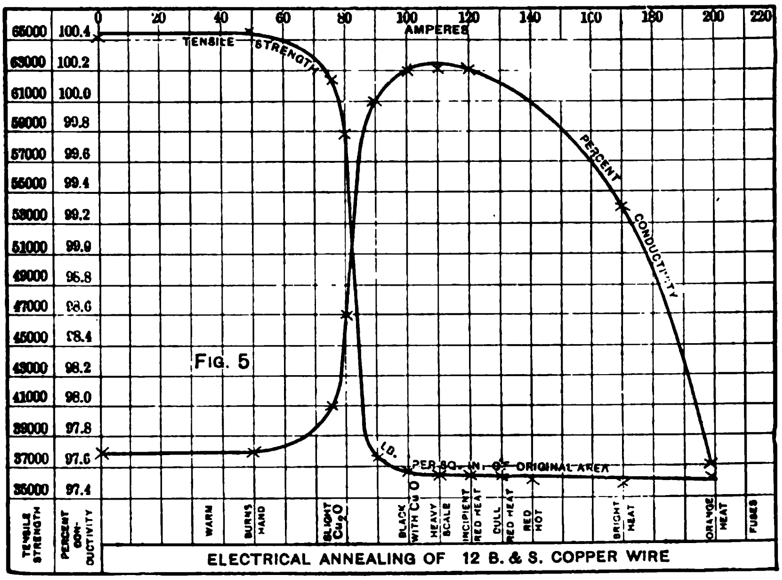


FIG. 5

The question at once arises whether the lower conductivity due to overheating is caused by the absorption of oxygen in some way or to a crystalline change. The first idea that suggested itself was to anneal the wire in such a way that oxygen could not attack it. Handling white-hot wire of the length needed in an atmosphere of nitrogen proved somewhat troublesome, however, and was left as a last resort. Silver-plated wire was tried but the plating would not stand the temperature Finally the problem was attacked in two different ways: First, samples of burned wire were immersed in dilute nitric acid until the diameter was considerably reduced and then measured for conductivity. No appreciable difference was found, showing that any chemical change was at least uniform throughout the wire; Secondly, samples of burned wire were drawn to a smaller size, re-annealed properly and then tested. The original wire, when properly annealed showed 100.4 percent conductivity; when burned for the test, 99.1 percent; and when drawn down and re-annealed properly, 100.5 percent. These results show the change to be of a physical, not chemical nature.

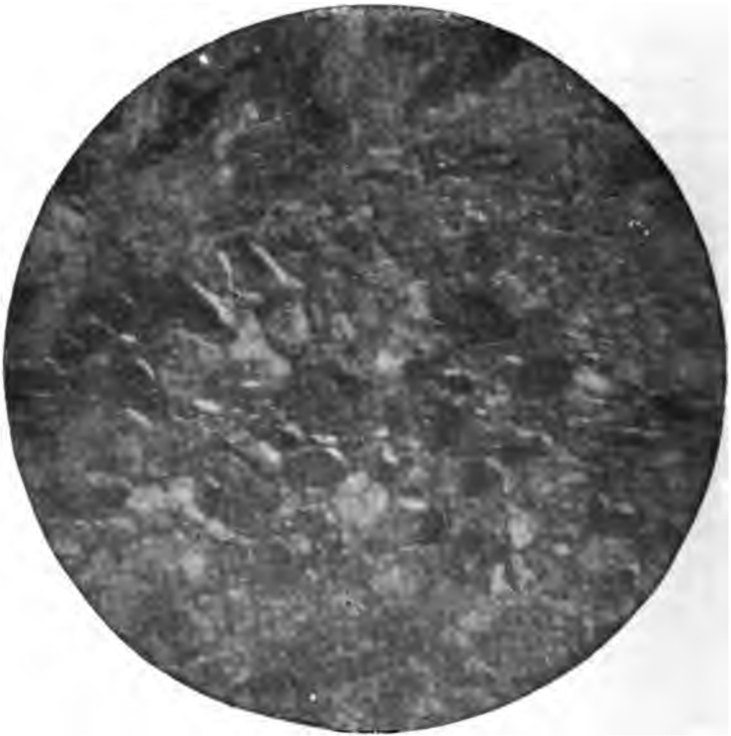


FIG. 6.—Good cast copper—X50.

Figs. 6, 7 and 8 are micro-photographs of copper samples which have been polished and etched in 50-percent aqua-regia for about 30 seconds. The magnification and the size of rod from which the samples have been cut are the same in each case. Fig. 6 shows good copper in "set", having a conductivity when drawn and annealed of 99.7 percent. Pure metals, when cast, crystallize on cooling into irregular grains the size and distribution of which depend largely upon the size of casting and rate of cooling. When small quantities of impurities are present they form a matrix of what is probably an eutectic alloy of the metal and the impurities, in which the grains of pure metal are set. This is the case with the sample under discussion where the total impurities amount to about one-tenth percent. Each of these grains is made up of smaller crystals, the cleavage being in different directions in grains. Fig. 7 shows a copper low enough in pitch to give trouble at the draw-bench. It is the lowest of the series of points on Fig. 2 and runs 96.4 percent annealed. The change in structure is at once apparent and accounts for the brittleness developed.

Fig. 7.—" Low " cast copper—X50.

When copper is rolled and drawn this granular structure is broken down, a fine fibre resulting. Fig. 8 shows a sample of trolley wire which has been heated over a gas-blast to a bright heat. It shows a partial return to the crystalline state, the matte surface in places having the same appearance as a hard-drawn sample as far as fibre is concerned. This explains the lowering of conductivity by overheating. The writer has never made measurements of the conductivity of cast copper, but understands from work done at one of the wire-mills that it has been found to run about 3.5 percent lower than the annealed wire. This is entirely in accord with the data shown above Copper that has been re-melted in the foundry may run but 30 or 40 percent, due to the absorption of gases.

In cast copper we have a conductivity resulting from the combined conductivities of the pure copper grains and the impure matrix or cement. When this is rolled the structure is broken down and the complex shunt and series circuits rearranged to better advantage. When hard-drawn, the molecular freedom is restrained and more work has to be done in the necessary oscillation of an atom in passing a charge on to its neighbor. In annealing, the wire is brought to a temperature at which the cement is softened and all internal strain is equalized. In burning, crystalline growth is started and reverts the metal to the original condition.

FIG. 8.—" Burned " trolley wire—X50

Discussion on Mr. Addick's Paper.

The President:—The paper just read gives much interesting information in regard to the properties of copper wire. Practically the only specification that engineers are able to use is that copper shall have a conductivity 98 percent of that of pure copper; all else is left to the manufacturer. If the author had embodied a specification for copper for railroad and lighting work, it would have been most beneficial.

F. J. Newbury:—The results given in this paper are confirmed by our work. Our test for the purity of copper is a conductivity test. Manufacturers of copper wire would greatly prefer that the specification should apply to the strands making up a wire, and not to the stranded wire as a whole; the resistance of the stranded wire is greater than that of the individual wires composing it, and the strength of the stranded wire is less. The difference, however, between the stranded wire and its component parts is not always the same; the component wires, if hard drawn, should have a tensile strength of 60,000 pounds per square inch, and a conductivity of 97 percent Matthiessen standard. The resistance of stranded wire will be approximately 3 percent greater, and this seems to be apparently the amount taken up in the twist of the wires, which indicates that the current follows the individual wires around the spiral. Commercial copper, as now made, is very nearly equal to the conductivity shown by the tables published by the Institute; in strength it varies from 52,000 to 65,000 pounds per square inch; 68,000 pounds is the maximum, and 60,000 for an ordinary specification is fair.

The President:—Engineers will probably not agree with Mr. Newbury in his preference for a specification of the component wires of a stranded wire; the engineer wishes to know the result to be expected from the wire, and cares little for the factors entering into it; he does not wish to have to make allowance for the manner in which the wire is made up. Possibly the matter of heating enters into the consideration of a stranded cable; a bare conductor will carry more energy than an insulated conductor. Is it not possible that the twisting of the wires reduces the conductivity a portion of that 3 percent?

A paper presented at the 181st Meeting of the American Institute of Electrical Engineers, New York, Nov. 20, 1903.

THE COMPARATIVE BEHAVIOR OF FLOATING AND BOOSTER-CONTROLLED BATTERIES ON FLUCTUATING LOADS

BY LAMAR LYNDON.

Methods of Application.—The object of using the storage-battery as a regulator on variable loads is to absorb, as far as possible, all fluctuations above or below the average current. When the external load is light, the generator sends current into the battery as well as to the external circuit. When the demand is heavy, the battery discharges in parallel with the generator, relieving the latter of the excess load. In some instances it is desired to maintain the generator current constant, eliminating the shock and strain of excessive and suddenly-imposed loads, and to secure the fuel-economy incident to steady loads as compared with fluctuating. In other cases, the object is to maintain a constant voltage on a circuit or rather to prevent it from varying more than a predetermined amount. Obviously, the maintenance of absolutely constant load, or voltage, is the ideal condition, and the more nearly this is approached the more nearly is the object attained.

Where the load is applied some distance from the power-station, there are five possible methods of installing a storage-battery to maintain the load on the generator reasonably constant, which are:

(1) Floating battery in power-station.

(2) Floating battery, out on line, at point of application of load.

(3) Battery with booster, in power-station.

(4) Battery and booster, out on line, at point of application of the load.

(5) Battery cut on line, at point of application of the load, and booster in the power-station.

Cell Characteristic.—Fig. (1) shows the characteristic of an 800-ampere-hour cell one-quarter discharged, at 70° F., in good condition. This will change with temperature, the characteristic more nearly approaching the horizontal with higher, and the perpendicular with lower, temperature. It will also change with state of charge, density of electrolyte, and condition of plates. The ordinates above the horizontal line which intersects the characteristic curve at zero represent the voltage of a cell on charge, and those below this line the volts on discharge, at various rates of current flow. The abscissas are amperes, the curve being extended on either side of the zero to that point where the current flow is equal to the one-hour rate of charge or discharge. Each reading was taken 20 seconds after beginning of the corresponding current flow. The zero point shows the voltage of a cell when current flows neither into nor out of it.

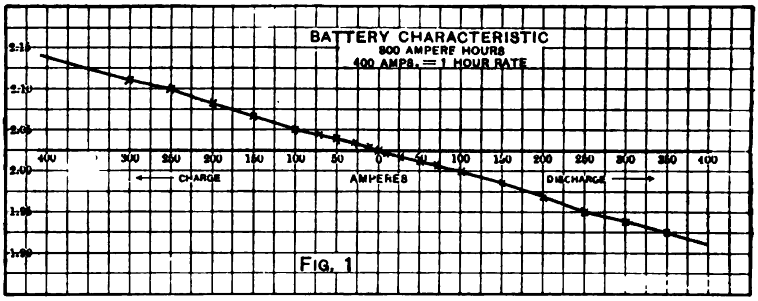


FIG. 1

This is the general form of characteristic for nearly any type or size of cell, the conditions of charge, temperature, density of electrolyte, etc., being the same. The data then to construct the characteristic for any size of battery of same state of charge, temperature, and density of electrolyte as given are:

Volts per cell at zero, 2.025; at the one-hour discharge rate 1.915, and at the one-hour charge rate 2.14. Connect these points by a straight line. The one shown is practically a straight line, and repeated tests on many sizes and types of cells indicate that if the conditions be maintained constant throughout a test, and due allowance be made for the error in reading the small changes in the voltmeter deflections, the characteristic is a straight line between the points of one-hour charge and one-hour discharge rates.

Conditions Necessary for Floating.—If a storage-battery be "floated" on a system on which the load is fluctuating, the voltage of the circuit across which it is connected must obviously vary with the load; rising above that of the battery when the demand is light and sending in a charging current; falling when the demand is heavy and allowing the battery to discharge and assist the generator.

In order that the system may work properly there should be a certain relation between the battery characteristic and that o the generator. The greater the inclination of the generator characteristic to the horizontal; that is, the greater the change in voltage with change in load, the greater will be the battery discharge on loads in excess of the normal or average load. Referring to Figs. 2 and 3. In Fig. 2 the generator characteristic has a certain inclination to the horizontal. The battery characteristic is superimposed on it, the point of zero current flow intersecting the generator curve at the point of normal load—600 amperes. For simplicity both are here assumed to be straight lines. When 1,000 amperes are sent over the line, the generator furnishes 880 and the battery 120 amperes, the increase in load on the generator being 280 amperes or 47 percent.

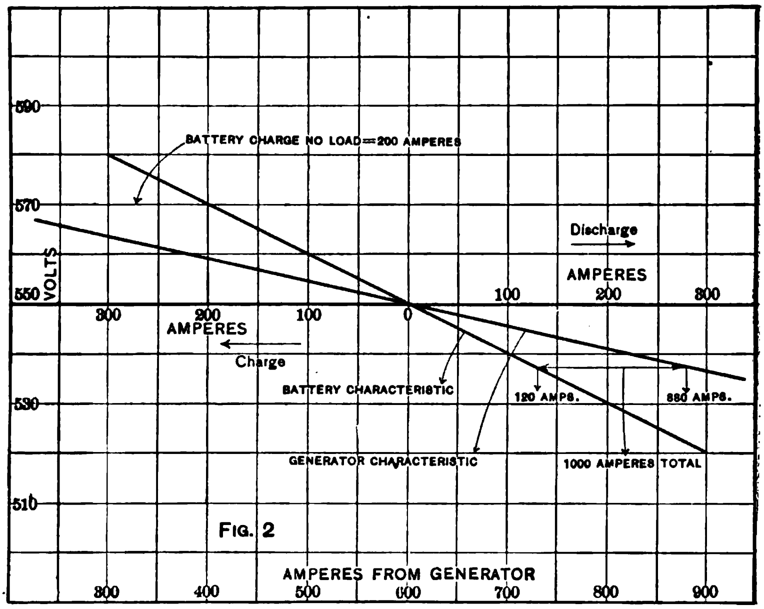


FIG. 2

In Fig. 3 the inclination of the generator characteristic is greater than in Fig. 2, and for 1,000 amperes station output, the generator furnishes 750 amperes, the battery 250, the increase of generator load above normal being 150 amperes or 25 percent. In the latter case, however, on light load, the voltage rises so greatly that an excessive current will pass into the battery, probably injuring it. As the one-hour rate of charge should never be exceeded—and even this should last but a very short time—the relative inclination of the two characteristics must come within certain limits. Furthermore, large shunt generators of high efficiency cannot be made—or at least certainly are not made—so that the full-load voltage decreases more than 15 percent below the no-load voltage. This limits the inclination of the generator characteristic.

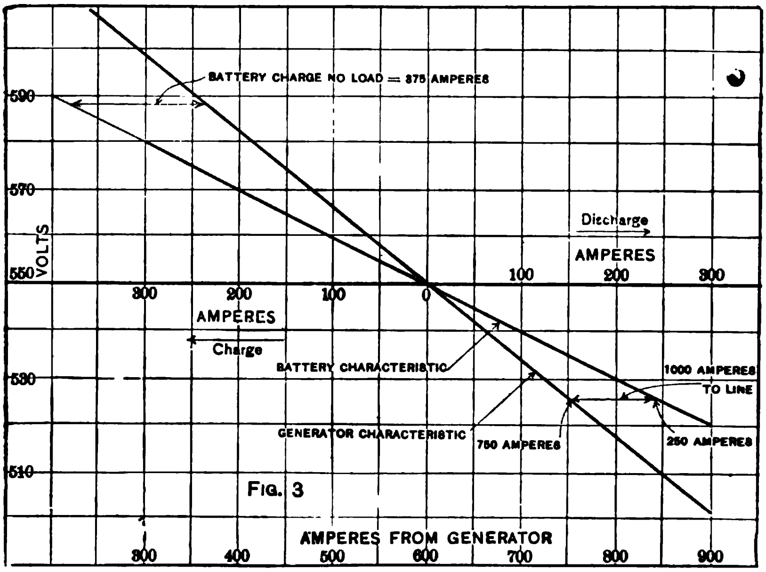


FIG. 3

CASE I.—FLOATING BATTERY IN STATION.

Data of System.—Consider the case of a fluctuating load such as is shown in Curve A, Fig. 7. The minimum current is 260, maximum 1,000, and average 600 amperes. Such a load coming directly on the generating equipment must result in low efficiency and high fuel-consumption per h.p. hour; and will require generators with large overload capacity and heavy engines to withstand the strains imposed. It may here be mentioned that the load-curve shown is not an assumed one, but represents the actual readings made on an operating electric railway.

Assume that this load is carried over one feeder to a point 2 miles from the power-station; that the minimum voltage at any time is to be 350 volts; that the track is of 70 lb. rail, well bonded. Still assuming both characteristics as straight lines, Fig. 4 is drawn. Line " I " is the generator characteristic. The dotted line running just underneath " I " is the characteristic of a 600-ampere-hour battery, the one-hour charge or discharge rate of which is 300 amperes. This line is in reality coincident with the generator curve. The voltage of the generator at normal load, 600 amperes, is 550 volts, which is also the open-circuit voltage of the battery. The ordinates are volts as indicated. The lower set of abscissas are amperes of generator output; the set on the horizontal line at 550 volts are amperes of charge or discharge of the battery.

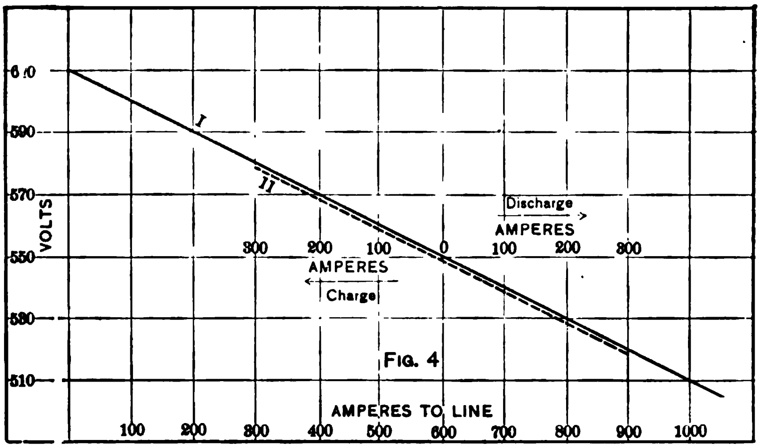


FIG. 4

Summation Curve.—Fig. 5 shows a summation curve which gives the station voltage at any output to the external circuit and is constructed as follows:

At voltage of 530 the generator output is 800 amperes, the battery discharge 200; total, 1,000 amperes to the line at this voltage. Similarly, at 540 volts the sum of the two outputs = 700 + 100 = 800; at 560 volts the generator output = 500 amperes and the current going into the battery = 100 amperes hence the line current = 500 – 100 = 400. Likewise, at 570 volts, line current = 400 – 200 = 200 amperes. In this way the points on the summation curve are located which give line current as the abscissas and station voltage as the ordinates. Since the characteristics are both straight lines, the summation curve is also a straight line. In this case only two points have to be located and joined together, but in many cases where the generator characteristic is a curve, the summation line becomes a curve and several points must be located to trace it. For this reason the method of tracing is here set forth.

Line Constants.—From Fig. 5 it may be seen that the station voltage at 1,000 amperes is 530 volts. Since the minimum voltage at the delivery point 2 miles distant must not fall below 350 volts, the total line-drop must not exceed 180 volts, which fixes the resistance at .18 ohm. The resistance of two miles of well-bonded 70 lb. rails is .0582 ohm. This leaves .1218 ohm as the copper resistance or .0609 ohm per mile, corresponding to 940,000 cir. mils. Taking this resistance, the curve of line-drop at various loads is plotted, which is shown in Fig. 6. This is, of course, a straight line.

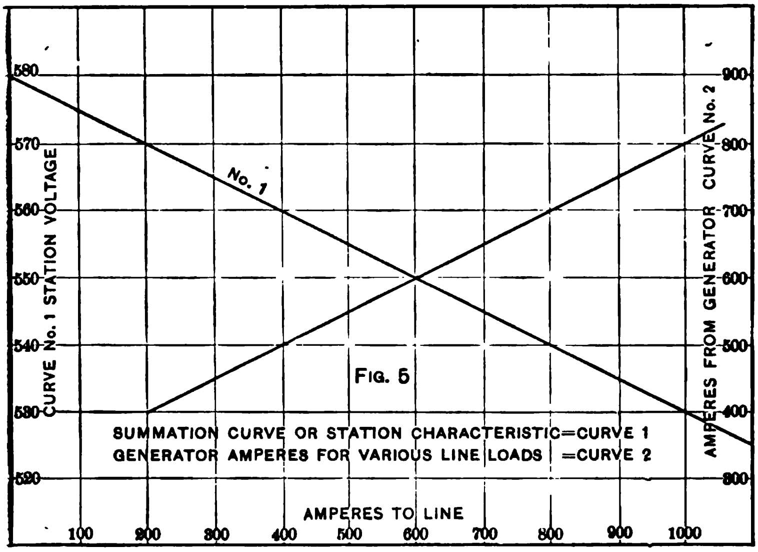


FIG. 5

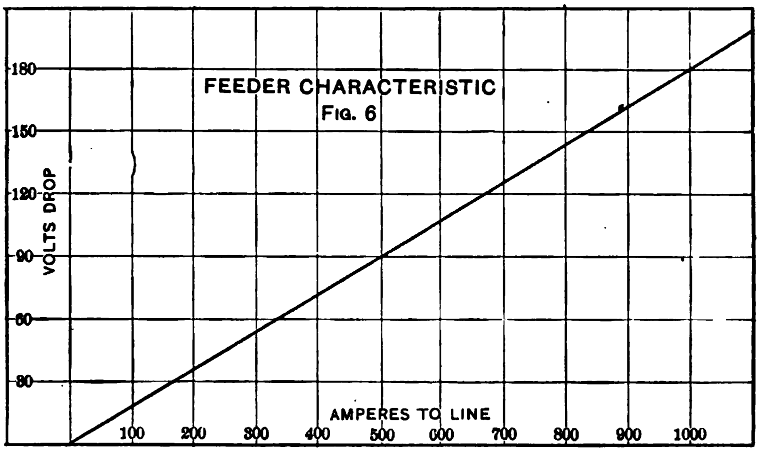
Derived Diagrams.—From the foregoing data and figures the curves in Fig. 7 are derived. Curve A is the load-diagram before mentioned; Curve B, the generator load; Curve C, the current to or from the battery; Curve D, the variation in station voltage with load, and curve E, the change of voltage at the feeding point, plotted by subtracting from the ordinates of D the feeder-drop for the various currents. Since all the relations are of the first order, the various curves are of the same form as the load-curve. Curves D and E are also of the same form, but reversed, being inverse functions of the load-curve.

A study of these curves reveals the following:

(1) The voltage at the station falls off rapidly with increase of load (Curve D, Fig. 7).

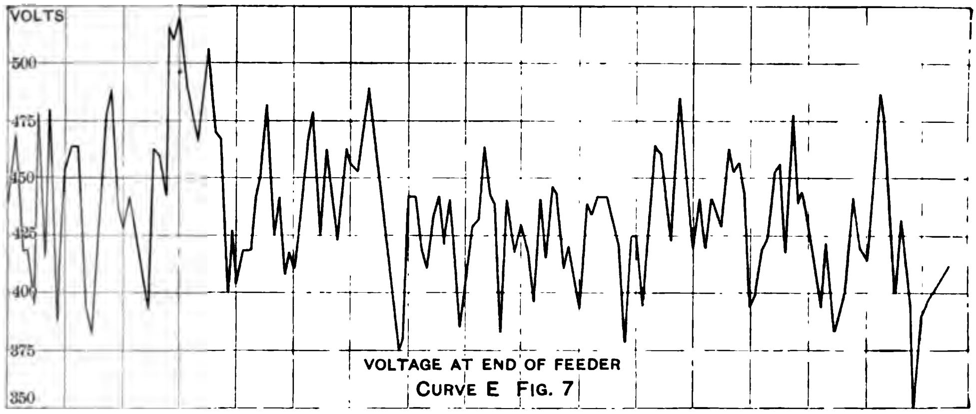
(2) Only two thirds of the capacity of the battery to discharge are utilized. It can discharge at the rate of 300 amperes, and only 200 amperes are drawn from it at the instant of the maximum peak (Fig. 4).

(3) Because of the fall in station voltage with load, the copper required on the line is excessive, and the voltage at the feeding-point unsatisfactory, as shown by Curve E.

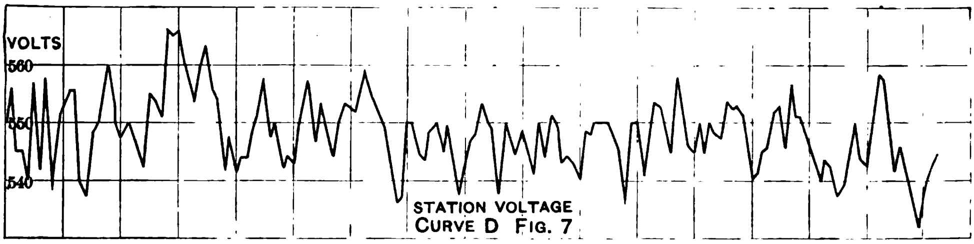

FEEDER CHARACTERISTIC
FIG. 6

(4) The fluctuations on the generator are greatly reduced, and the capacity of the generating equipment may be decreased in the ratio of 8 to 10, or 20 percent.

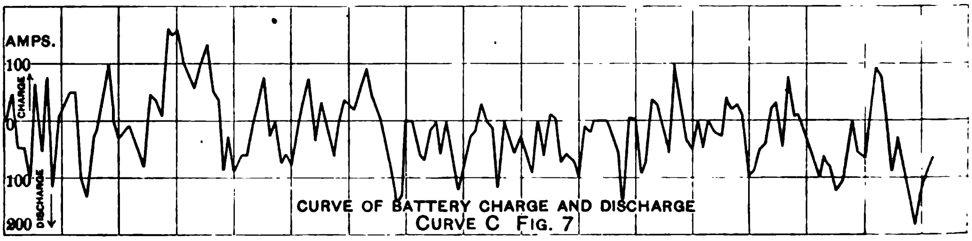
Drooping Generator Characteristic.—All the foregoing is based on straight generator characteristic. As a matter of fact, however, it would be of the form shown in Fig. 8. This change, from a theoretical straight characteristic to the actual drooping one, introduces complications. If the battery characteristic intersect that of the generator at the point of normal load—600 amperes—as indicated by the dotted line, the discharge on heavy loads will be greater than in the previous case, since the inclination of any element of the curved portion to the horizontal is



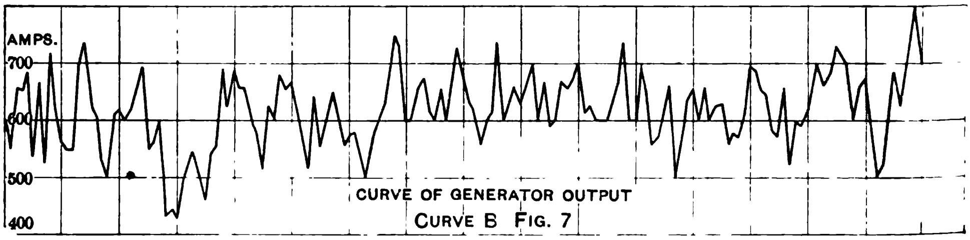
VOLTAGE AT END OF FEEDER
CURVE E FIG. 7



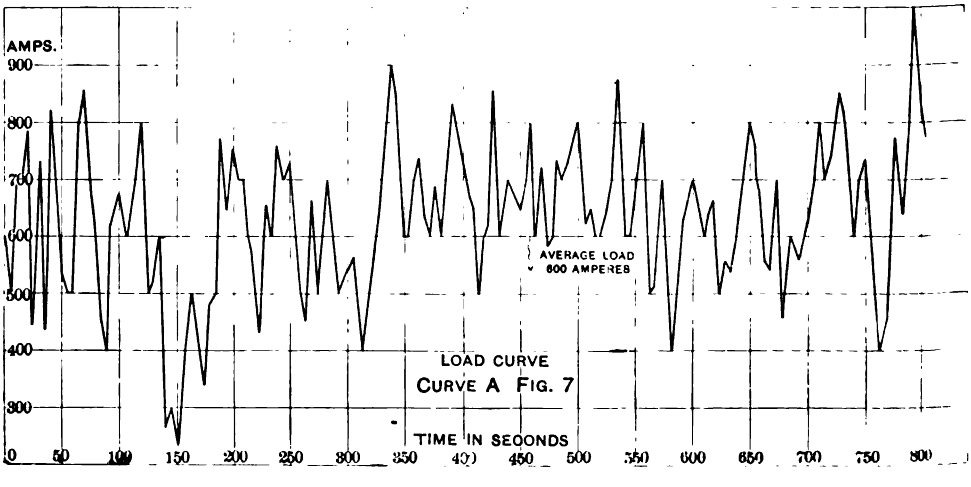
STATION VOLTAGE
CURVE D FIG. 7



CURVE OF BATTERY CHARGE AND DISCHARGE
CURVE C FIG. 7



CURVE OF GENERATOR OUTPUT
CURVE B FIG. 7



LOAD CURVE
CURVE A FIG. 7

greater than that of the straight-line characteristic, and a larger portion of the load will be taken by the battery. But it may also be seen that with the same light loads as before, the battery-charging current is less than in the previous case.

Relation between Input and Output.—In any battery used for regulation, it is necessary that the input approximately equal the output, otherwise the state of battery charge is changed and the efficiency of the regulation decreased. If the input exceed the output, the excess energy will be lost, going off in the form of free gases from the cells, and the high voltage due to overcharging decreases the current which may be sent into the battery on light load, thus permitting more fluctuation of the generator load. Furthermore, continuous overcharge will ruin a battery, if persisted in.

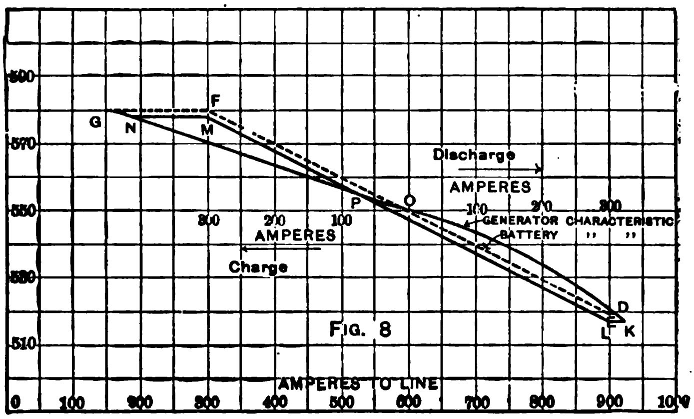


FIG. 8

If the output exceed the input, electrical bankruptcy follows and the battery is in no condition to help the generator when most needed.

From Fig. 8 it may be seen that the input and output are to each other inversely as the two areas on either side of the intersection of the generator and battery characteristics, which are formed by the spaces included between the two characteristics and closed by horizontal lines which are drawn through the points of voltage at maximum charge and discharge. That is, the areas O D E and O F G are to each other inversely as the battery input is to the output. The point O is not necessarily the intersection with the line of average external load, but is the point of intersection of the two characteristics. Obviously, therefore, the battery characteristic must be moved downwards, increasing O F G and diminishing O D E until these two areas are equal, the resulting areas being P M N and P L K. This means that the normal battery voltage is lowered, its zero point being shifted downwards. With the normal load of 600 amperes on the line, there will now be a charging current into the battery of 20 amperes, making the generator current 620 amperes and lowering the station voltage to 548 volts.

Conditions with Drooping Characteristic.—The conditions are then manifestly less advantageous in the actual case than in the theoretical case first discussed and in either case are worse than they would be with an over-compounded generator in the power-station working without a battery. The mere reduction of mechanical strains and fuel-consumption are of little avail if the cars on the system cannot be accelerated, carried over grades and schedules maintained.

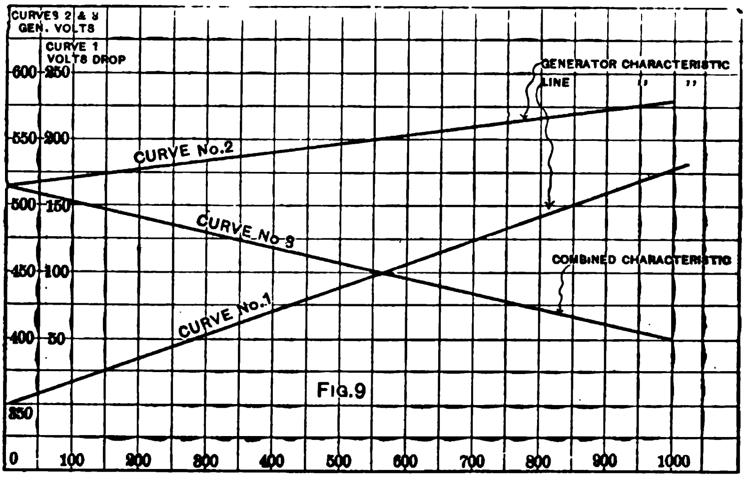


Fig. 9

Compound Generator.—For comparison with the previous cases, Figs. 9 and 10 are shown. In Fig. 9 are plotted the characteristic of an over-compounded generator, the line characteristic with resistance .18 ohms as before and a combination of these showing the total characteristic for the feeding-point. From this last, the curve in Fig. 10, which is the voltage curve at the feeding-point, is plotted. This is drawn to the same scale as Curve "E," Fig. 7, and a comparison of these two curves shows the superiority of the over-compounded generator working alone. The minimum voltage in the former case is 350, in the latter 401; and the maxima are 522 and 482 volts respectively. If 350 volts are sufficient for satisfactory operation, the resistance of the circuit may be increased from .18 to .23 ohm. Deducting the track resistance, .0582 ohm, the copper resistance becomes .1718 ohm which corresponds to 665,000 cir. mils, as against 946,000 cir. mils. in the first case—a reduction of 29 percent.

CASE II.—FLOATING BATTERY OUT ON THE LINE.

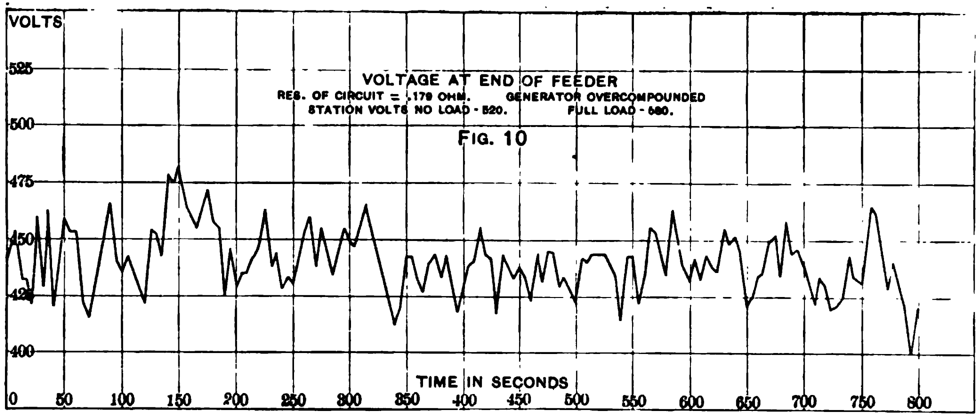
Data of System.—Consider now the case of a floating battery located at the feed-point—2 miles away from the station: Assume an over-compounded generator giving 520 volts at no load, and 580 volts at full load of 800 amperes, and assume further that the battery will discharge 200 amperes at maximum load of 1,000 amperes, giving 800 amperes as the maximum transmitted over the line. If the minimum voltage allowable be 350 volts, the resistance = .287 ohm or .2288 ohm for the copper resistance, corresponding to 495,000 cir. mils. or 25 percent less copper than that required in the case of the compound-wound generator working alone.

Fig. 11 shows the generator characteristic, the line characteristic, the combined characteristic, and the characteristic of a 600-ampere-hour, 392-volt battery. This shows that when the maximum load of 1,000 amperes comes on the system the generator supplies 700 amperes, the battery 300, and the voltage is 371.

Derived Diagrams.—In Fig. 12 are shown the summation curve of Fig. 11, giving the voltage at the feeder-point for any current to the line, and the line No. 2 which shows the relation between the amperes flowing over the line and the current from the generator. Fig. 13 shows the three curves· B the load on the generator; C the current to or from the battery, and D the voltage at the feed-point all for the same load curve shown in A, Fig. 7. All these are to the same scale as the corresponding curves in Fig. 7 and may be readily compared therewith.

Excessive Rate of Charge.—The only objectionable feature in this system is, that the charging current, if the load on the line should reduce to zero, would be far in excess of the permissible rate. This is shown in both Figs. 11 and 12. In Fig. 12 the voltage at zero line-load is seen to be 425 volts, which on the combined characteristic in Fig. 11 corresponds to a current-flow over the feeder of 450 amperes. If there is any possibility of the line ever being relieved of load, some provision must be made for avoiding this excessive charge. In the system under discussion, however, this never occurs.

Results.—The location of a floating battery at the feeding-point shows manifest and undoubted improvement in that



VOLTAGE AT END OF FEEDER
RES. OF CIRCUIT = .179 OHM. GENERATOR OVERCOMPOUNDED
STATION VOLTS NO LOAD - 520. FULL LOAD - 580.

FIG. 10

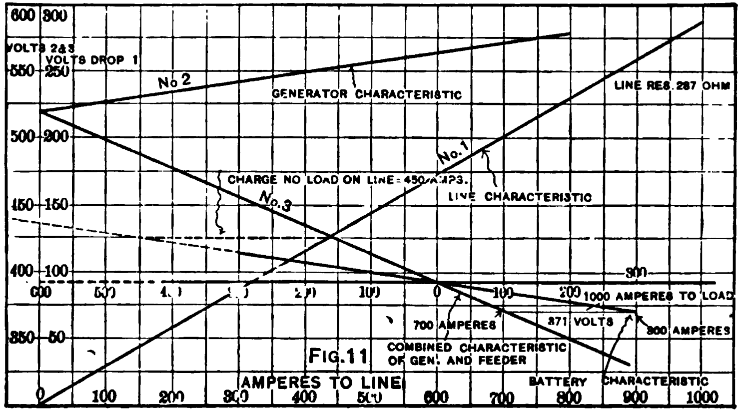


FIG. 11

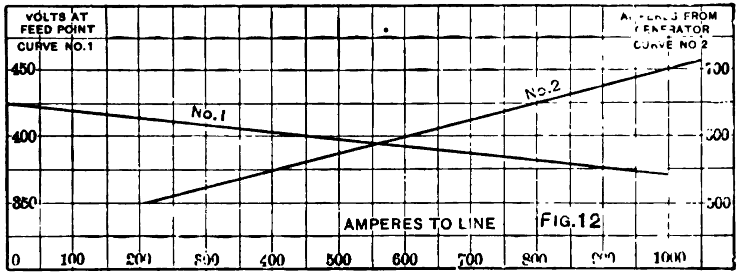


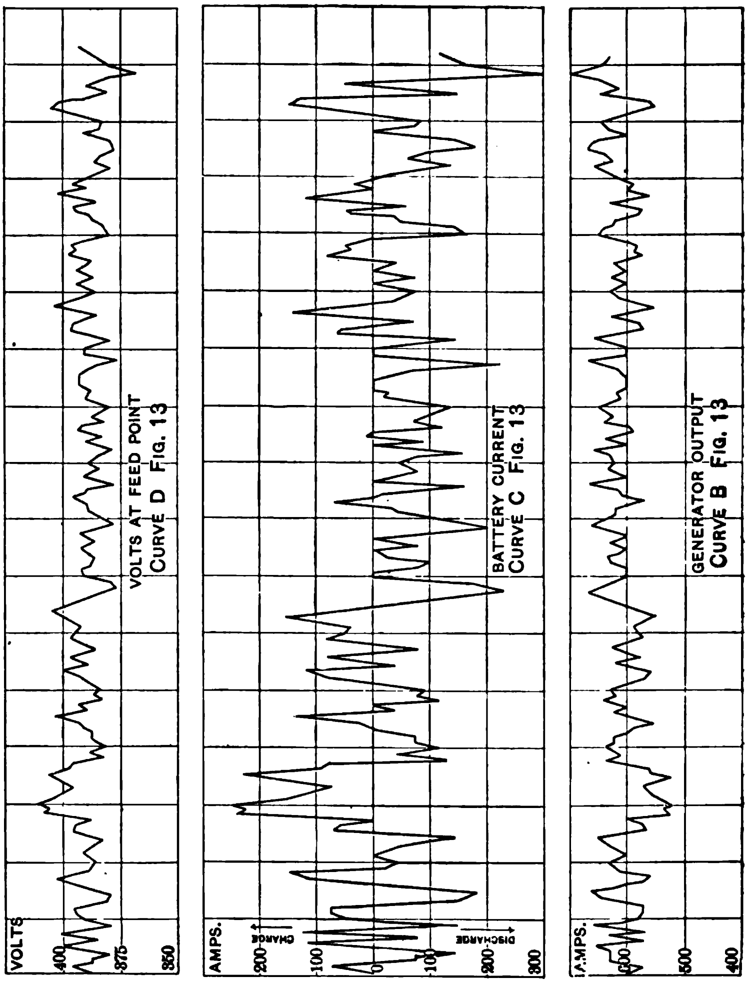
FIG. 12

it not only performs all the functions of equalization with the production of the accompanying benefits, but the copper and size of generator are so much decreased that the saving is greater than the cost of the battery, so that the first cost of the system is less than in the case of a generator without the battery auxiliary.

It is to be noted that the voltage at the feeding-point, with average line-load, is 392 volts, which is also the open-circuit voltage of the battery. In the case of the battery located in the power-station, the floating voltage required is 550. The number of cells in series in the former instance is 194, and in the latter 271; so that the cost of the battery is diminished in this ratio, or 28 percent. Also this changes the slope of the battery characteristic. The 550-volt battery shows 30 volts increase above normal for the one-hour charge rate, and the same amount below normal for the one-hour discharge rate. In Fig. 11 it may be seen that the variation above or below normal for the one-hour rate of charge or discharge, is, 21.5 volts due to the smaller number of cells in series. The change in the voltage of the individual cells is, of course, the same in either case.

Overcharge.—In practice it is necessary to overcharge or "boil" the cells occasionally to maintain them in good condition. The voltage on overcharge rises to about 2.6 volts per cell or 30 percent more than the normal voltage. Thus a battery which has a floating voltage of 550 volts would require a potential of 715 volts at the terminals to give a proper overcharge. Since it is seldom possible to increase the station voltage to such a figure, it becomes necessary when " boiling " to connect the battery so that it is divided into two portions, each having an equal number of cells in series. These two halves are then connected in parallel across the line. As the voltage required to overcharge is now halved, proper resistances must be inserted between each set of cells and the line. Generally, the ordinary water-barrel rheostat is used. Since overcharge need only be given ten or twelve times a year, this is not a continuous condition of operation.

Where the battery floats at the end of a long feeder of fairly high resistance, which is heavily loaded, the normal battery voltage is lower than that of the station, and during the early hours of the morning, when for half or three quarters of an hour the load may be thrown off the feeder, the decrease in feeder-drop, together with full generator excitation, may bring the voltage at the battery terminals up sufficiently high to give it the required overcharge. In the case just cited, the voltage at the feed-point with 75 amperes passing over the line (which current is ample for boiling a 600-ampere-hour battery) is 502 volts. The potential required at the battery is 194×2.6 = 503 volts. A very slight increase in the generator voltage will, therefore, meet the requirement, if the feeder be entirely relieved of other load.



COMPARISON CASES I. AND II.

The results, then, of locating a battery out on the line as compared with the use of the generator working alone are:

(1) Load on generator is maintained much more constant as indicated in Curve B, Fig. 13.

(2) Copper cost is greatly reduced.

(3) Voltage varies much less, and with less copper the minimum voltage is increased.

Also the full capacity of the battery is utilized, which was not the case when floated in the station.

BOOSTER SYSTEMS.

In discussing the operation of the two batteries previously considered with booster auxiliaries, it is proper here to indicate how, and under what conditions, automatic boosters operate. There are two generic types of regulating boosters: One in which slight changes of line voltage cause changes in field excitation to produce charge or discharge; in the other the field excitation is varied by the changes in external load.

Fig. 14 shows an example of the first-mentioned type: G is a shunt-wound generator, B the booster armature, E the battery, and M M the motors or variable load on the system. The driving-motor is not shown. The operation of this booster is as follows: At normal load, the voltage of the battery and line are equal, and as no current flows either into or out of the former, the series field, S, is not excited and the booster voltage is zero. On increase of external load, the generator tends to send out additional current, causing a slight decrease in line voltage. The battery then begins to discharge and the field, S, being energized by the outgoing current, induces an e.m.f. to assist the discharge, or in other words, adds an e.m.f. to the battery e.m.f., equal to the drop due to discharge. This added e.m.f. compensates for the battery-drop whatever the rate of discharge, since both vary directly as the outflowing current. Conversely, if the load decreases, the line voltage will rise slightly, causing the beginning of a charge. The direction of the current now being reversed in the coils, the e.m.f. produced in the booster armature is also in the opposite direction and assists in forcing the charge into the battery. Since the rise in battery voltage on charge and the booster e.m.f., both increase proportionally to the current, the rise in battery .e.m.f. is practically compensated for. Therefore, within small percentages the voltage is maintained constant, regardless of the rate of battery charge or discharge, and from this it follows that the load on the generator is also kept constant. Obviously, this booster is operative only on systems having a falling characteristic with load increase; that is, with a shunt generator, if the battery is located in the power-house or on a feeder, the drop through which exceeds the increase in voltage at the generator terminals, if the system is fed by a compound-wound dynamo.

The second type of booster is shown in Fig. 15. In this the battery voltage is equal to that of the line, and at normal load the excitation of the series field s, which is in the external circuit, is exactly equal to that of the shunt field *f*. These being oppositely wound, neutralize, and the booster voltage is zero. If the external load be increased, the excitation of s overpowers that of *f* and there results a booster e.m.f. proportional to the increase in external load and in a direction to cause the battery to discharge.

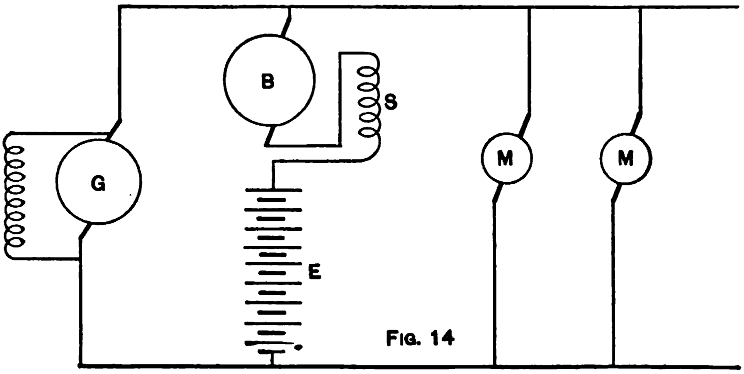


FIG. 14

Should the load decrease, the shunt field is the predominant one and produces an e.m.f. in the booster armature to cause a charging current to flow into the battery. This booster can be used either with shunt or compound-wound machines.

These diagrams merely illustrate the salient principles of booster operation, and are not complete practical devices, as additional windings are required to produce points of stable equilibrium and prevent excessive charge or discharge. There is a large number of different types having various windings and connected in ways peculiar to the ideas of the inventors, or the limiting factors of existing patents. These two, however, show the principles on which they all work.

CASE III.—BATTERY WITH BOOSTER IN POWER-STATION.

Since with a booster-controlled battery, the generator load is kept practically constant, it matters little what kind of generator is used in the power-station, it being only necessary to settle on the best average station voltage. Assuming 550 volts as the desired e.m.f. at the station, a 550-volt battery, the same load and general conditions as in Case I, the size of battery is to be determined. Since the average load is 600 amperes, and the maximum 1,000, a battery to discharge 400 amperes is required. If the one-hour rate is not to be exceeded, an 800-ampere-hour battery is necessary. The maximum load, however, comes on the system but infrequently, as shown by the load-diagram, and as it lasts only 5 seconds, a 700-ampere-hour battery, having a one-hour rate of 350 amperes, will be ample as it will only have to give out 17 percent in excess of its rating, and then for a negligible time. Even a 600-ampere-hour battery would work satisfactorily on this load.

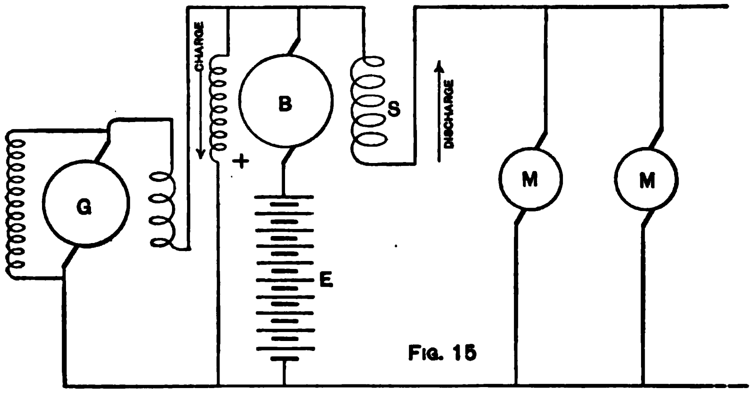


FIG. 15

Assuming a 700-ampere-hour battery in the station, practically all the fluctuations in load will be absorbed and the generator load-curve becomes a straight, or rather a wavy line. The station voltage being constant, the feed-point e.m.f's at various line-loads are not quite so satisfactory as are furnished by a compound-wound generator. If the minimum voltage at the feed-point is to be 350, the resistance must not exceed .2 ohm or .1418 ohm for the copper resistance, requiring 805,000 cir. mils. as against 665,000. The generating equipment, however, is reduced in size from 550 kw to 350 kw and the fuel economy greatly increased.

COMPARISON OF CASES I. AND III.

As compared with the shunt-wound generator working with a floating battery in the power-station, the generating equipment is 330 kw as against 440; the copper, 805,000 circular mils as against 945,000; the load variation 6 percent as against 47 percent; the voltage variation at the feed-point 19 percent as against 20 percent—these two factors being practically equal, because of the greater amount of copper in the line fed from the floating battery.

CASE IV.—BATTERY AND BOOSTER OUT ON LINE.

If the floating battery out on the line has a booster auxiliary working with it, the current passing over the feeder will be maintained constant, and the average load only will be transmitted from the power-station. If, as in the previous cases, the voltage is not to fall below 350 volts, the resistance (assuming 550 as the generator voltage) will be .333 ohm total or .2751 ohm for the copper; equivalent to 415,000 cir. mils. This, however, is not so advantageous as it seems, for the voltage at the point where the booster is located is constant and the e.m.f. will neither fall below 350, nor will it rise above it. Taking 420 volts as a satisfactory pressure, the resistance of the line becomes .217 ohm = .1588 ohm for the copper = 720,000 cir. mils. This allows the maintenance of a satisfactory potential which varies so slightly as to be practically constant.

COMPARISON OF CASES II. AND IV.

Compared with the floating battery on the line, the booster-controlled system gives a higher and more satisfactory voltage; the copper is 720,000 cir. mils. as against 495,000 cir. mils. This is not a real comparison, however, in view of the higher voltage maintained. The load on the generating equipment is kept constant within 6 percent as against a variation of 17 percent; the power-house capacity required is 330 kw against 385 kw.

While the booster-controlled battery out on the line is theoretically superior to a similar equipment in the power-station it requires. extra attendance; which in many cases offsets its advantages and makes it advisable to put the booster and battery in the station and add a little more copper to the line, or install a floating battery at the feed-point.

Furthermore, the usual condition in practice is that of a power-plant supplying current to numerous feeders, no single one of which carries sufficient current, or is enough longer than the others to warrant a battery installation only to take care of its load and voltage. Generally, therefore, in order to regulate the station load, the battery and booster must be in the power-station.

The advantages shown by the booster-controlled batteries over those floating across the circuit, do not include a most important one; namely, the ability to obtain full battery discharge even when the stored energy in the cells is nearly exhausted and the voltage decreased below normal. The battery characteristic (Fig. 1) shows that the minimum voltage, when discharging at the hour rate, is 1.915 volts per cell. This is the case only when the battery is worked nearly fully charged, and the output and input are so nearly equal, that the state of battery charge is practically unchanged. If, however, any unusual condition or event should raise the average load on the system, the output might exceed the input for several hours, and the battery becomes so far exhausted that the voltage would fall to 1.7 per cell when discharging at the one-hour rate. This is a decrease of .215 volts per cell—or 58 volts in a 550-volt battery—below the minimum voltage of discharge when the battery is worked near the point of ull charge. Obviously, without a booster the battery in this condition would not be of any assistance at all in the power-station. and its regulating ability out on the line greatly impaired.

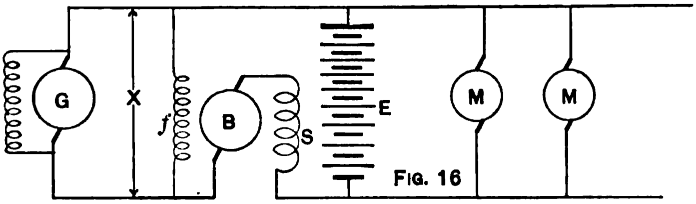


FIG. 16

Another advantage offered by the booster is, that the necessary overcharge is not attended by a troublesome manipulation of water-barrels, with the usual accompaniment of heavy grate-bars and a jug of sulphuric acid.

CASE V.—BOOSTER IN STATION; BATTERY ON LINE.

The final method of installing the battery, that is, with the booster in the power-house and the battery out on the line, is peculiar, in that only one type of booster may be used, and there must be a separate feeder from the booster to the point where the battery is located. In the foregoing discussions, a single feeder from the power-station to the feed-point has been assumed, to simplify the comparison, which is just as valid in its results as if the load had been distributed over the length of various feeders. If the circuits in the cases discussed were merely a simple trolley and track with distributed loads, any of the four described applications could be used, except that the booster system shown in Fig. 15 would not be suitable as the auxiliary for the battery floating on the line.

Character of Booster.—A particular arrangement of the type of booster shown in Fig. 15, causes it to allow only a practically unvarying current to pass through its armature. Referring to Fig. 16, G is the generator; B the booster armature; *f*, a shunt field; S a series field; E the battery, and M M the motors or variable load. The voltage across the mains at X is obviously the generator voltage, while the potential at the terminals of M M is equal to the voltage at X plus that of the booster. As in the case of the booster shown in Fig. 15, the shunt and series fields are in opposition; but at normal load, the magnetization of the shunt field exceeds that of the series field, and an e.m.f. is generated in the booster armature, which is added to that of the generator to produce normal voltage across the mains. The battery being connected directly across the mains, its normal voltage is equal to that of the generator, plus booster.

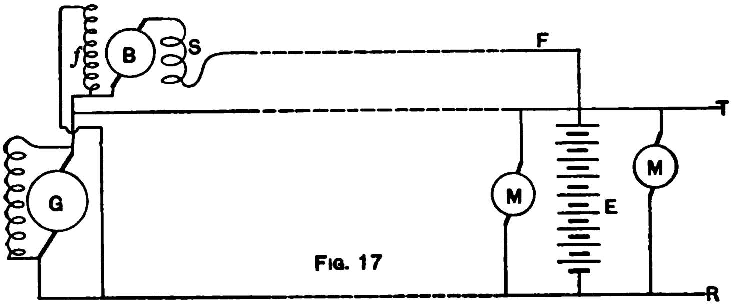


FIG. 17

If an excess load should come on the system, the generator tends to send additional current to the line, strengthening S and reducing the booster voltage and, consequently, the potential across the mains. The battery then discharges. The converse occurs on increase of load; the booster voltage rises, and current flows into the battery. This system allows only a constant current to pass through the booster armature and is therefore known as the constant-current booster.

In Fig. 17 is shown the method of applying this machine to the case in hand. The symbols are the same as in Fig. 16; T is the trolley, R the track and F the feeder from the booster. The shunt coil *f* is connected across the line and coils in series with the feeder F.

Line-Drop.

In Fig 18. the curve A represents the voltage which obtains along a line fed from one end, and with the load uniformly distributed along its length.

In the figure, the drop at the distance L, from the source of is seen to be 350 volts. If from P only one half the circuit is supplied with current, there will be a decrease in drop due to lowered resistance, and a further decrease due to the fact that only one half the current flows over the feeder. If the distributed load from P to E is 1,000 amperes and the drop 350 volts, the load over one-half the distance is 500 amperes and the resistance of the circuit one half that from P to E, so that the drop is one fourth of 350 or 87.5 volts, if the circuit extend only to N. This shows that the drop at the end of a main supplying a distributed load varies directly as the square of the distance over which it feeds.

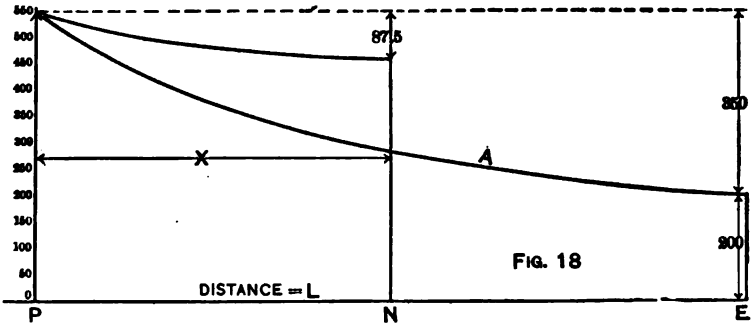


Fig. 18

Data of System.

Assume the same conditions as in previous cases and shown in Fig. 19, taking the load as being equally distributed along the line, which in this case, however, is 5 miles in length instead of 2 miles, as before. Computations for drop on a 2-mile line with this system show the cross-section of the copper to be so small that it has not the requisite current-carrying capacity. The copper which extends along the entire length of the circuit will be taken as 400,000 cir. mils. inclusive of the trolley wire. The resistance per mile of circuit is .1424 ohm for the copper and .0291 for the track, making .1715 ohm per mile, or .8575 ohm total. The drop on distributed load is 429 volts at the far end of the line when 1,000 amperes pass over it. This is shown by Curve No. 1 in Fig. 19. It is desired so to place the battery on the line as to reduce the drop to 150 volts, putting the booster in the power-station, and adding such an amount of copper as may be necessary.

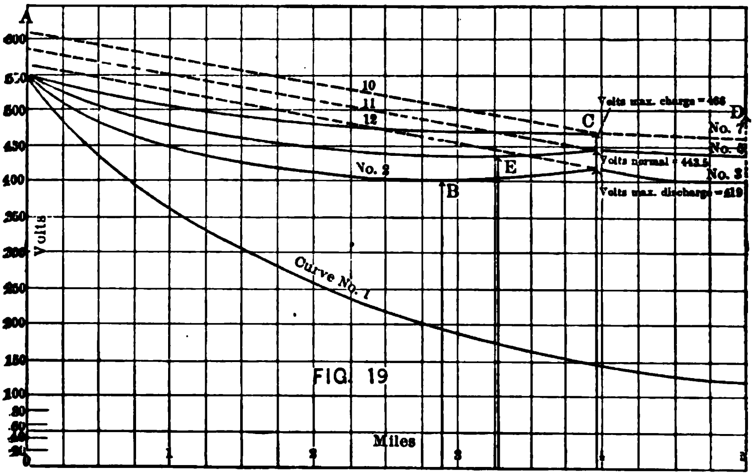


FIG. 19

Location and Voltage of the Battery.

Since the drop from the power-station varies as the square of the distance over which a distributed load is supplied, the distance, X, to which the original copper can feed at a drop of 150 volts, is computed by the proportion:

$$X^2 : (5)^2 : : 150 : 429, \text{ from which}$$

$$X = 2.89 \text{ miles, which is shown at point B.}$$

The remaining distance, or 2.11 miles, is to be divided into two equal parts and the battery so located that it will feed in each direction 1,055 miles, which is its distance from the end of the line. Point C. shows its position. Its voltage is fixed by the condition that the line voltage must not fall below 400 volts. Applying the above proportion:

$$(5)^2 : 429 : : (1.055)^2 : Y$$

$$Y = \frac{429 \times (1.055)^2}{(5)^2} = 19.1 \text{ volts}$$

= drop for the distributed load on either side the battery, which is located at C. 19.1 + 400 = 419.1 = battery voltage when discharging at maximum rate or 1,915 volts per cell.

$$\frac{419.1}{1.915} = 219 = \text{No. of cells in series.}$$

$219 \times 2.025 = 443.47$ = voltage at C, with normal load on system, battery neither charging nor discharging, 2.025 being the open-circuit voltage per cell as shown in the characteristic (Fig. 1). Voltage per cell is 2.14 when charging at maximum rate.

$2.14 \times 219 = 468$ = volts at battery at maximum charge.

Changes with Load Variations.

As the load decreases and the voltage rises, the distance that the line will feed toward the battery is increased as shown by curves 4 and 6, while curves 5 and 7 show the corresponding rise of potential at the end of the line. At normal load of 600 amperes total, the minimum voltage is 440 and the point of lowest potential has moved outward to E, the station now feeding from A to E. When the minimum load of 260 amperes is supplied the current from A to C is $\frac{260 \times 3.96}{5} = 207$ amperes The drop at this load is only 71 volts, making the line voltage at C, 479, which is 11 volts higher than that of the battery on charge. Therefore, the line will supply all current from A to C, and also send enough into the battery to bring the voltage of the line at C down to 468; which extra current to the battery is $\frac{11}{0.6774} = 16.3$ amperes, 0.6774 being the resistance of the circuit from A to C.

The point E and the voltage at that point are computed as follows: The general formula for distance to which each of two sources of current will feed where both supply the same line at a fixed distance from each other and where the line carries a distributed load is

$$X = \frac{L}{2} + \frac{V_1 - V_2}{a\,r\,L} \text{ in which}$$

V_1 is the voltage of the source having the higher potential.

V_2 the voltage of the source having the lower potential.

L = distance between the two sources in feet.

a = amperes of distributed load per foot of line.

r = resistance per foot of circuit taken over single distance of transmission.

X = distance in feet to which the higher voltage source will feed.

$L-X$ = distance to which the lower voltage source will feed.

In the case under consideration the quantities are as follows:

$L = 3.96$ miles $= 20{,}880$ feet.

$V_1 = 550$ volts.

$V_2 = 443.47$ volts.

$$a = \frac{600}{5 \times 5280} = 0.02278 \text{ amperes per foot}$$

$$r = \frac{0.1715}{5280} = 0.0000325 \text{ ohm per foot.}$$

$$X = \frac{20880}{2} + \frac{550-443.47}{0.02278 \times 0.0000325 \times 20{,}880}$$

$$= 17270 \text{ ft.} = 3.27 \text{ miles.}$$

which is the distance of E from A. The current distributed over the line to E is $\frac{600 \times 3.27}{5} = 392.4$ amperes. The resistance of this length of circuit is $0.1715 \times 3.27 = 0.56$ ohm. The drop then to E $= \frac{392.4 \times 0.56}{2} = 110$ volts, making the voltage at E 440 volts, when the normal current flows over the line.

Feeder to Battery.

The total current to that portion of the system past E away from A, must be supplied by the feeder F (Fig. 17), and this current Z is determined by the proportion.

$(5-3.27) : Z :: 5 : 600$, whence

$Z = 207.6$ amperes.

The size of the feeder F is now to be decided on. If its current-carrying capacity be sufficient to allow 207.6 amperes to flow, its resistance is of little moment so far as the operation of the system is concerned, since the voltage of the booster can be made sufficiently high to compensate for any feeder-drop. This resistance, however, is commercially a serious factor, since the booster energy input is lost. The question then is to determine the most economical cross-section of copper, which is beyond the scope of this paper. For purposes of the discussion assume it to be 400,000 cir. mils,; resistance .1424 ohm per mile. Resistance of circuit $= .1424 + .0291 = .1715$ ohm per mile; or $.1715 \times 3.95 = .6774$ ohm, total. The drop then to C $= .6774 \times 207.6 =$

140 volts. $443+140 = 583$ = voltage of generator plus booster at the station. $583-550 = 33$ = booster voltage when average load is on the line. Since the current is practically constant, the drop to C may be considered constant, hence for variation of battery voltage to cause charge or discharge, the booster voltage must vary as indicated at A. The straight lines 10, 11, 12 show the drop along the feeder.

Battery Capacity.

Since the battery regulates 2.11 miles of the system, the average current as shown is 207.6 amperes, while the maximum $\frac{1000\times 2.11}{5} = 422$ amperes. Therefore, the one-hour discharge rate should be $422-207.6 = 214.4$ amperes, making the battery capacity 430 ampere-hours. The constant current from the booster, however, must be taken care of. On light load the generator is furnishing all crurent up to C, and also 16.3 amperes to the battery, making 223.3 amperes flowing to this point. The current consumption from C to D is only $\frac{260\times 1.055}{5} = 54.8$ amperes; $223.3-54.8 = 168.5$ amperes, going to the battery which should not be in excess of the one-hour rate of charge. This necessitates the use of a 340-ampere-hour battery, which is less than the capacity required for the maximum discharge.

Results.

This system then distributes current over five miles with a maximum current of 1,000 amperes: the minimum voltage is 400, the average 440, the fluctuations on the system are from 260 to 1,000 amperes, on the generator from 431 to 785.6. This is accomplished by the use of 9 miles of 400,000 cir. mil. feeder, a 12½ kw. booster, a 450 kw. generator, and 261 cells of 430-ampere-hour capacity.

This paper has covered, it is true, only one set of conditions, but from it can be learned the method of investigation applying to any particular set of conditions; and it also shows that the setting forth of any general formulas or deductions to be applied indiscriminately is practically impossible.

Appendix.

Deduction of formula

$$X = \frac{L}{2} + \frac{V_1 - V_2}{a\,r\,L}$$

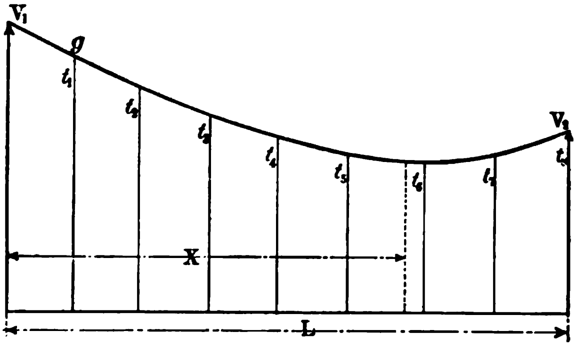


Fig. 20.

In Fig. 20 the heights of V_1 and V_2 represent the respective voltages of two sources of e.m.f.; t_1, t_2, t_3, t_4, etc., taps or points at which current is taken from the line. L is the distance apart of the two sources. X is the distance over which the source V_1 will feed, and $L - X$ the distance over which V_2 will feed. Let t_x represent the point which is X distance from V_1 and $L - X$ distance from V_2. Obviously at the point t_x the voltage of V_1 minus the drop from it to t_x = voltage of V_2 minus drop from it to t_x. Assume d as the distance apart of the taps; r as the resistance of the circuit from one tap to the next succeeding one, and a as the number of amperes taken from the line per tap.

The drop then from V_1 to t_1 represented by the curve $V_1\,g$ is equal to the total amperes supplied by V_1, multiplied by the resistance from V_1 to t_1 or drop to $t_1 = n\,a\,r.$, n being the number of taps from V_1 to t_x and $n\,a$ the total current flow from V_1 to t_1.

The drop from t_1 to t_2 is equal to $(n - 1)\,a\,r$ and from t_2 to t_3 = $(n - 2)\,a\,r$, and so on, the last drop being $= a\,r$. The total drop from V_1 to t_x is the sum of all these. Since d is the distance apart of the taps $\frac{X}{d}$ = number of taps from V_1 to t_x and the drop from V_1 to t_x $= a\,r + 2\,a\,r + 3\,a\,r + \frac{X}{d}\,a\,r$. This being an arithmetical progression the sum is equal to one-half the sum of the first and last terms multiplied by the number of terms; that is, $D_1 = \dfrac{\left(a\,r + \frac{X}{d}\,a\,r\right)\frac{X}{d}}{2} = \dfrac{a\,r}{2}\left(\dfrac{X}{d} + \dfrac{X^2}{d^2}\right)$

D_1 being the drop from V_1 to X
Calling D_2 the drop from V_2 to X
$V_1 - D_1 = V_2 - D_2$, from which
$D_1 = V_1 - V_2 + D_2$

$D_2 = \frac{a\,r}{2}\left\{\left(\frac{L-X}{d}\right)+\left(\frac{L-X}{d}\right)^2\right\}$ this being derived in the same way as was the value of D_1.

Substituting;

$$\frac{a\,r}{2}\left(\frac{X}{d}+\frac{X^2}{d^2}\right)=\frac{a\,r}{2}\left\{\left(\frac{L-X}{d}\right)+\left(\frac{L-X}{d}\right)^2\right\}+\left(V_1-V_2\right)$$

whence

$$X = \frac{L}{2}+\frac{(V_1-V_2)\,d^2}{a\,r\,(1+L)}$$

If the distance apart of the taps be taken as unity, say one foot; d^2 becomes equal to one and disappears from the numerator, and since d is negligible compared to L, it may, in practice, be omitted and the formula becomes

$$X = \frac{L}{2}+\frac{V_1-V_2}{a\,r\,L},$$

If it be assumed that t_x coincides with some tap point, which receives one-half its current from V_1 and the other half from V_2 and a = amperes per tap, the drop from V_1 is

$$\frac{1}{2}\,a\,r+\frac{3\,a\,r}{2}+\frac{5}{2}\,a\,r\cdots\left(\frac{X}{d}-\frac{1}{2}\right)a\,r,$$

and the sum $= D_1 \doteq \dfrac{\left\{\frac{1}{2}+\left(\frac{X}{d}-\frac{1}{2}\right)\right\}\frac{X}{d}\,a\,r}{2} = \left(\dfrac{X^2}{d^2}\right)\dfrac{a\,r}{2}$

Similarly:

$$D_2 = \left(\frac{L-X}{d}\right)\frac{a\,r}{2}, \text{ and}$$

$$\frac{a\,r}{2}\left(\frac{X^2}{d^2}\right)=\frac{a\,r}{2}\left(\frac{L-X}{d}\right)^2+V_1-V_2$$

whence

$X = \dfrac{L}{2}+\dfrac{(V_1-V_2)\,d^2}{a\,r\,L}$ and if d be taken as unity—say one foot

$$X = \frac{L}{2}+\frac{V_1-V_2}{a\,r\,L}$$

a and r being respectively the amperes supplied and the resistance of the circuit per foot of distance between the two sources of e.m.f.

Discussion on Mr. Lyndon's Paper.

J. R. Appleton:—The value of a battery for relieving the strain on the generators with fluctuating loads is well illustrated by a plant at Oakland, California. The station equipment comprises one 600- and one 850-kilowatt generator; without the battery it was essential to keep a man at the throttle of each engine, on account of the rapid variations of load; with the battery, the 850-kilowatt generator maintains the load between 700 and 800 amperes continually, and the battery supplies current up to 2,600 amperes; that is, a constant load is kept on one generator, and the other generator becomes a spare unit.

J. L. Woodbridge:—It may be worth while to point out that the function of a battery at the station is different from that at the end of a feeder. The station battery will keep the station load constant and regulate the station voltage; the feeder battery will not hold the station voltage constant to any material extent, and will not reduce the load fluctuations materially.

W. E. Goldsborough:—The introduction of a storage-battery at a center of distribution of the St. Louis Rapid Transit Company's system has made a saving in copper which pays for the installation of the battery and all the auxiliary machinery used in connection with it.

J. W. Lieb:—Though not immediately germane to the paper, it may be worth while to point out the very great importance of a storage-battery in a large alternating current generating station to supply field excitation. It is imperative that batteries should be installed for this purpose which may be thrown instantly on the field circuit to take the place of the other exciters; for this purpose, the battery capacity should be large. The speaker has made a test on a large plant with several 4500 kw. alternators in parallel, throwing out the motor-generator exciters and throwing the whole exciter equipment on the battery; there were practically no fluctuations in the bus-bar voltage. In the speaker's opinion, it is also imperative that the storage-battery should be used as a reserve in any general direct-current distribution system supplying a large population and obtaining current from a high-pressure transmissoin plant, the possible causes of interruption to service are so numerous that such a system cannot be considered safe without a very large reserve in battery.

W. W. Donaldson:—A battery on a line should be installed so that the greatest possible amount of work will be done by the battery· if it discharges only once a day, it is not doing as much work as it should. This question of amount of use during the day should be given consideration.

W. E. Goldsborough:—A battery should unquestionably be adjusted to give the maximum return to the equipment with which it is connected. A battery supplies a means for keeping all the apparatus working at the point of maximum efficiency, from the central station, through the sub-stations, and on to the line. In a large system, the small loss of energy in the battery is unimportant in comparison with the reduction of depreciation which it brings about in all other parts of the system.

A. S. **Hubbard**:—In a railway power-station, the average load is not the same at different periods of the day. A booster should be capable of adjustment to change the average load supplied by the generator. If a battery is proportioned for the daily average, it will be far larger than necessary to care for the momentary peaks; by proportioning the booster so that the average load, as represented by the generator load, can be raised or lowered, as conditions demand, the size of the battery may be reduced. A similar consideration applies to the floating battery when the car schedule is changed; but on a system using a constant-current booster in a power-station with a separate feeder to the battery, a change of schedule can be cared for by changing the booster output. Further, if a battery is operated on a daily average, its efficiency is far less than if operated for comparatively short periods—say, of two or three hours.

Lamar Lyndon:—The various points presented by the different speakers, while interesting, do not seem to be directly germane to the paper in hand. There is therefore nothing to be added to the statements of the paper.

BRANCH DISCUSSION.

Discussion on Mr. Lyndon's Paper at Pittsburg, December 3, 1903.

F. L. **Flanders**:—Mr. Lyndon says that a battery should not be worked above its one hour rating, and even then only for moderate periods. This rating was established by the largest battery company because its cells cannot be used safely at greater rates. Batteries of the Planté type, made in Germany, do, however, work at much higher rates. The following test was made on a cell of this type, having a capacity of 1000 ampere-hours at the eight-hour rate: the cell was discharged at 4000 amperes for 30 seconds; then allowed to rest for 20 seconds; then discharged at from 400 to 500 amperes for five minutes; then allowed to rest for 10 seconds. This completed a cycle, which was immediately repeated. This test was continued day and night for six days of the week, for two and one-half years, and at the conclusion, no depreciation of the cell was to be seen. In Germany it is customary to work at much higher discharge rates than in the United States, but only for short periods.

The 200-ampere Edison cell is now on the market. For the same power, this cell occupies 17% more space than a lead cell, but for the same weight it gives 40% greater output. The pressure of the Edison cell at discharge is 1.3 volts at first, falls rapidly to 1.25 volts, and after reaching 1.1 volt drops in about 15 minutes, to 0.7 volts, and five minutes after falls to 0.5 volts; it continues at this for some time, and then suddenly goes " down and out." The average voltage of the cell is 1.2. The efficiency of the Edison cell, worked at maximum capacity, is about 35%, but with careful charging and discharging, the efficiency may run as high as 60 per cent.

The principle advantage of the Edison cell claimed by the makers is that it is " fool-proof;" it may be left in any condition of charge without damage; it may be charged and discharged at any rate. As no life tests of the cell have been published, the endurance under this treatment cannot be stated. An automobile equipped with these cells is guaranteed to run 70 miles on one charge, but about 20 hours are required to recharge the battery to obtain so great an output; from 40 to 50 miles is said to be a common run.

H. ETHERIDGE:—The majority of transmission lines in this territory are operated with the differential booster, in which the line current passes through the series field of the booster, as shown in Fig. 15 of Mr. Lyndon's paper.

The average efficiency obtained from our storage-battery is approximately 85%, possibly slightly higher. In some cases where the transmission line has failed, the battery has been placed across the line to supply the service until the line could be repaired and again put into service; in such cases the efficiency probably falls to 60 per cent. We have verified the manufacturer's guarantee that the batteries when operating under normal conditions would exceed 85% efficiency. The deterioration of some of the positive plates of the cells seems, however, to be excessive. In some cases, those which have not been in use more than 18 months show strong signs of deterioration. The negative plates seem normal. The positive plates showing signs of deterioration are in cells that were short-circuited by allowing small globules of solder to fall between the plates during process of " burning " the plates.

We get very satisfactory conditions in operating our battery and differential booster. In the operation of batteries we do not find that they require excessive attention. The scaling is of small matter, the renewing of the electrolyte is easily accomplished; specific gravities and temperatures are taken every day and we are thereby enabled to detect a cell that may be short circuited by scaling. The life of these cells depends very largely upon the way in which they are treated; under average conditions it is safe to allow 10% depreciation for the positive plate. The cell, negative plate, and the electrolyte are of course good for a much longer period.

A paper presented at the 182d Meeting of the American Institute of Electrical Engineers, New York, December 18, 1903.

OVERHEAD HIGH-TENSION DISTRIBUTING SYSTEMS IN SUBURBAN DISTRICTS.

BY GEORGE H. LUKES.

The problem of building up and operating a satisfactory distributing system for the suburban towns and villages surrounding a large city presents many peculiar difficulties. The problem is more often to reconstruct an existing system, making use of as much of the old work as possible and at the same time making provision for future growth. Obstacles are usually encountered in the work. Many different interests have to be satisfied, and in some cases the engineer is compelled to use construction which is not desirable, but is necessary under the circumstances. It is seldom that the engineer is given the opportunity to lay out a complete system which can be operated economically and safely with a reasonably low first cost.

The villages surrounding a large manufacturing city are of several different types. The oldest ones are located on the lines of steam railways radiating from the city, and are residential in character. As transportation facilities are improved new suburbs are started at greater distances from the city. The older ones become more thickly settled and even grow to be cities themselves. Some of the villages are made up of people of moderate means, whose houses are fairly close together. Others are built up by wealthy people who buy tracts of land and build large houses, which they occupy but four or five months in the year. Later on, the manufacturing suburb makes its appearance, consisting of a group of factories and a small business district surrounded by the houses of the workmen.

In the process of time, electric lighting plants are erected in the larger villages and their pole lines are extended to the smaller villages near by to supply incandescent and street lamps. A large proportion of these small plants cannot be operated at a profit, and the result is a gradual deterioration in the stations and distributing systems, resulting finally in consolidations which bring large districts under the control of one company. It then becomes necessary to tie the various systems together, operating some of the stations as peak-plants and turning others into sub-stations, thus taking advantage of the fact that the peak may occur in the summer in one village and in winter in another.

Suburban business is so scattered that the cost of underground work is prohibitive and the distribution must be made by overhead wires. Public opinion is, however, intense in its opposition to overhead construction. The suburbanite objects to the multiplicity and unsightliness of the pole lines. He is in business in the city where the agitation against overhead wires has resulted in their being placed underground, and he refuses to believe that conditions are different in the country. In many communities local action has been taken compelling the use of joint lines by the electric light and telephone companies. These have been erected and operated successfully in many cases without any great danger. Joint lines should be avoided if possible, and it is important that every effort be made to make the pole lines unobtrusive. The poles should be well painted with a dull color, such as a dark olive-green, the wires kept taut and the connections made in a neat and symmetrical manner.

An overhead distributing system must be constructed so that the service will be reliable and not subject to frequent interruptions. The voltage regulation must be as good as possible, and danger to life and fire risk reduced to a minimum. This can be accomplished without adopting an extremely expensive method of construction. The great proportion of accidents and interruptions are caused by defects which are very easily guarded against, provided they are looked for. It is not the intention here to lay down rules for the construction of pole lines, but to draw attention to certain points which experience has shown to be often neglected.

Main Lines and Branch Circuits.—Main lines leading from stations should be on not less than 40-foot, and preferably on 45-foot poles. This gives plenty of room for additional circuits and makes it easier to cross above telephone and telegraph lines.

The branch circuits can be on shorter poles, but it is not advisable to use poles shorter than 30 feet. Where branch lines are taken off, the poles should be double-armed and buck-armed. Transformers, fuses, lightning-arresters and other devices should not be installed on main lines where it can be avoided.

Poles.—In the middle West, the poles available at present are Michigan white cedar and Idaho cedar. Michigan poles are better proportioned than western poles and are longer lived. Michigan poles should have a top diameter of not less than seven inches. If western poles are used, eight or nine inch tops should be specified in order to obtain proper butt diameter. Michigan poles are sorted and sold under the specifications of the Northwestern Cedarman's Association and it is therefore cheaper to buy under the above specifications and sort out to suit. Poles should be shaved, roofed, and given one coat of paint in the yard. Poles are painted in order to improve their appearance, but the question of whether or not it adds to the life of the pole is an open one. In setting, particular care must be taken to select the best poles for the corners, turns, and ends of the line. If the line is on a highway that curves, set as many poles in a straight line as possible and make the turns on one or two poles, which can then be properly guyed. A line that changes its direction at every pole can never be held in position. Poles should be double-armed at corners, curves, and ends.

Guying.—This is one of the most important features in pole-line construction and is often neglected. Corners, junctions, and ends should be carefully guyed. Wherever the line changes in direction, even if the change is very slight, a guy should be placed. Patent guys and land-anchors should be used with great caution and only on light work. The best guy is the old-fashioned one consisting of a guy-stub, set at some distance from the pole with a galvanized-iron anchor rod-bolted to a slug buried in the ground. Strain insulators should be inserted in the guy-wire and care be taken to make sure that the anchor-rod and guy-wire attached to it are grounded electrically.

Cross-arms.—The best cross-arms at present are made of southern yellow pine. They should be straight-grained, well-seasoned, free from knots, and purchased unpainted. They are the first part of the line to give out. The action of the sun's rays causes the arms to crack on top and they soon rot around the pin-holes. The usual method of treating is to paint them with white lead and oil, but in the West cross-arms boiled in carbolineum have been used to some extent. The matter of the proper dimensions and pin-spacing for cross-arms has not received the attention it should, and it is high time that an attempt be made to standardize 4-, 6- and 8-pin arms for use on circuits up to 5,000 volts. The proper 6-pin arm for such use should have approximately the following dimensions: section, 3½ inches by 4½ inches; length, 8 feet; spacing, between pins about 16 inches, between pole-pin about 22 inches. Cross-arms for junction-holes should be of special size with greater distance between pins.

Insulators.—The ordinary deep-groove, double-petticoat insulator has proved satisfactory on 2,000-volt incandescent and 4,000-volt arc circuits. It is perhaps advisable to use triple-petticoat insulators on 4,000-volt polyphase work.

Fuse-blocks and lightning-arresters are sources of trouble on pole lines. In some instances systems have been operated entirely without fuse-blocks on the outside lines excepting, of course, the transformer blocks. The best plan is to install them on branch lines where there is a chance for trouble. Lightning-arresters should be installed to protect groups of transformers and branch lines. They should be frequently inspected and the ground-wires tested.

Transformers should be hung on double-arms below the lowest arm. If they are of large size the arms should be extra heavy and bolted securely to the pole. Methods of bringing the primary wires down from the circuit to the transformer are various and all are open to objections.

It is usually impossible to keep a regular arrangement of circuits upon cross-arms for the reason that as the business grows circuits of all kinds are added. It is very desirable, however, that circuits be kept in the same relative position throughout their length in order to facilitate tracing. Houses should be, as far as possible, grouped upon three-wire secondaries which should be carried alone on the lower arm. The installation of 200–400 volt, three-wire secondaries would facilitate this work wonderfully in scattered districts. The neutrals of three-wire secondaries should be grounded on the first pole away from the transformer.

All series alternating arc lamps should be provided with absolute cut-outs and high-voltage insulators in the lowering cable. Windlasses for raising and lowering lamps should be permanently grounded and an arc lamp when suspended from span-wires should be connected so that should it fall, the lamp will not fall toward the windlass but away from it.

The importance of frequent inspections of pole lines cannot be overestimated Old pole lines can be made very reliable, provided they are well guyed and weak points kept in repair. For inspection work, linemen of considerable experience are needed, because only long years spent in repair work gives the ability to predict where trouble is likely to occur.

Accidents caused by overhead wires are remarkably infrequent, considering the number of miles of pole lines operated. They occur most often to electric-light linemen, less often to telephone linemen and very rarely to citizens. Accidents to linemen can largely be prevented by employing on live work only steady and tried men, and using the inexperienced men and floating linemen on new construction work. Accidents to telephone linemen are mostly the result of want of care on the part of the men themselves. Accidents to citizens can be reduced to a minimum by care in constructing and maintaining lines.

The danger from fire is in the posibility of high-voltage current reaching buildings; first, through defective transformers, and secondly, through crosses between primaries and telephone wires. The first can be eliminated by grounding the secondary; the second can be made remote by proper coöperation between electric light and telephone companies in the erection of junction poles and substantial construction at crossings; the danger from fire is somewhat overestimated and it is to be sincerely hoped that any restrictive regulations will not only be carefully considered before final action is taken, but worked out in actual practice to determine whether or not their enforcement would introduce risks which would more than offset any advantage gained.

A paper presented at the 182d Meeting of the American Institute of Electrical Engineers, New York, December 18, 1903.

AUTOMATIC APPARATUS FOR REGULATING GENERATOR AND FEEDER POTENTIALS.

BY E. J. BECHTEL

Since the introduction of electricity as a source of illumination, one of the most important problems has been that of potential regulation; for the efficiency of the conversion of electricity into light depends greatly upon the maintenance of a constant potential at the lamp terminals. For instance, a system having a potential regulation of two per cent can profitably use incandescent lamps which consume 3.1 watts per mean horizontal candle-power, based on the oval-filament type of present quality, while a poorer regulation-factor would require the use of lamps consuming from 3.5 to 4 watts per candle-power, representing a sacrifice of from 12.5 to 30 per cent in conversion efficiency.

The potential of a shunt-wound generator drops very materially as the load increases. To overcome this drop, compound-winding of generators was introduced, being a step towards automatic potential regulation; but this only compensates for the inherent loss in the generator itself and is not capable of regulation for speed-losses nor for variations due to outside causes. Thus, if it is desired to maintain a constant potential at the switchboard or center of distribution under changes of any or all conditions, an external automatic potential regulator must be used.

There are a number of types of automatic generator potential regulators using different methods to accomplish the result. One type, the connections of which are shown in Fig. 1, has been in use in our station for the past four years on generators up to 250-kilowatt capacity operating under extreme conditions. This regulator has given excellent service in alternating-current work, as will be seen by examining the curve on a section of recording-voltmeter chart shown in Fig. 2. This line was made by a 150-kilowatt, 60-cycle, alternating-current generator, supplying current for the daylight incandescent load and operated from a jack-shaft driven by an engine which also operates a direct-connected 500-kilowatt, 500-volt, direct-current generator, supplying current for the street railway system. The larger part of the engine-load being very irregular, and the engine-governor not of the best, there are sudden fluctuations in speed, as shown by the section of curve from a continuous-speed recorder in Fig. 3. Each vertical section of the record has a value of 20 seconds, or three sections per minute. Each horizontal section has a value of three per cent in speed variation, or two cycles in the frequency of the generator. The variation of speed shown would not be advisable on inductive loads, but serves to show the efficiency of regulators under severe conditions.

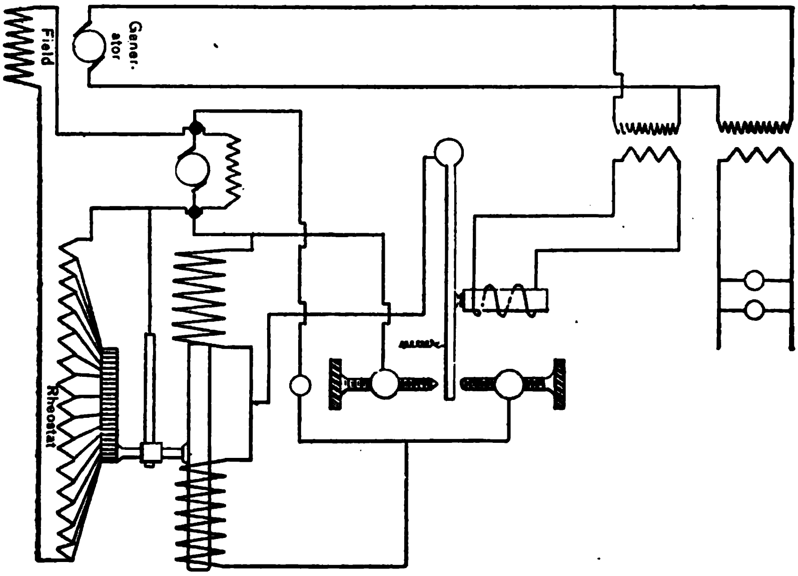


FIG. 1.

This type of regulator, while very satisfactory as a generator potential regulator, and perhaps sufficient under favorable line and load conditions in small stations, does not correct the potential for variation in power-factor nor relative changes in the load on different feeders.

The system was adopted while our alternating load was comparatively small and operated from single-phase generators. With the intention of operating three-phase power circuits, we replaced the small single-phase generators with larger ones of three-phase 4,000-volt, four-wire type, the armature being star-connected with neutral connection brought out.

The 2,300-volt, single-phase lighting circuits are connected to the different phases and neutral, balanced as nearly as possible between the different phases in regard to load conditions. Even with extreme care, a perfect balance cannot be maintained on account of variations of load at different times on the individual circuits. To overcome this, we have ordered nine automatic feeder potential regulators of the boosting transformer type, having the secondary winding in series with the circuit and divided into small sections which are capable of being automatically cut in or out, step by step, as the conditions require, to maintain a desired voltage at the individual feeder terminals.

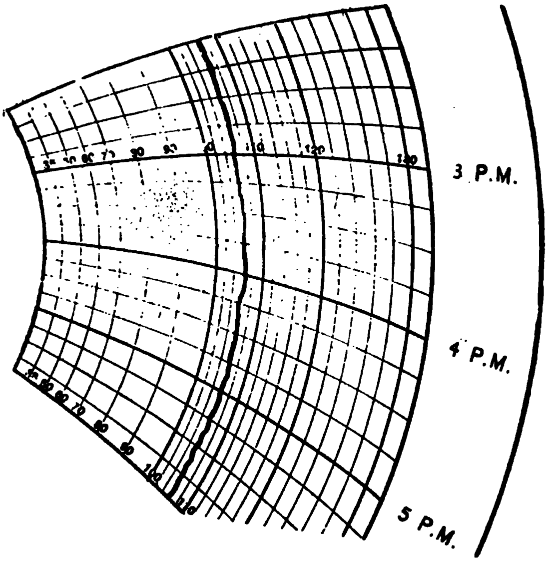


Fig. 2.

These regulators are to have necessary capacity to maintain a pressure of ten volts (200 volts primary) above or below that of the bus-bars. The installation of this apparatus has been delayed by the manufacturer on account of trouble experienced from pitting or burning of the contacts. I am sorry I am not able to show results of tests on this apparatus and describe its action under practical conditions, as I had intended to do.

Feeder potential regulators are not advisable for use on direct-current systems on account of it being necessary to use batteries, rotary-boosters, or dead resistance in series with the different feeders—any one of these being a most inefficient arrangement.

However, this problem is not so serious, as the entire system can be formed into a network and operated as one unit. Good distribution and regulation can be obtained by the use of a system of interconnected mains, tied together wherever possible with feeders from high and low bus-bars to determined points, and by use of main storage-batteries.

The automatic generator potential regulator first described as being satisfactory on alternating-current work, was not satisfactory on a direct-current, three-wire system. We installed two of these regulators on a pair of 200-kilowatt generators for the purpose of steadying the potential of a three-wire system of about 2,000 kilowatts at peak-load; but they are not capable of doing this, nor even capable of maintaining a potential regulation of less than from 2 to 4 per cent while operating on a separate load. The greatest fault is the tendency to surge or pump (even with a properly adjusted oil-cushion), probably on account of the greater sluggishness or time required to increase or decrease the magnetic density of the solid field-poles of the direct-current generator, as against the laminated field-poles of the alternator. I believe, however, that a later regulator now on the market is capable of maintaining a uniform potential under these conditions, being quicker in its action; as, instead of cutting small steps of resistance, step by step, in or out of the field-circuit, it cuts a large resistance instantaneously in or out of the field-

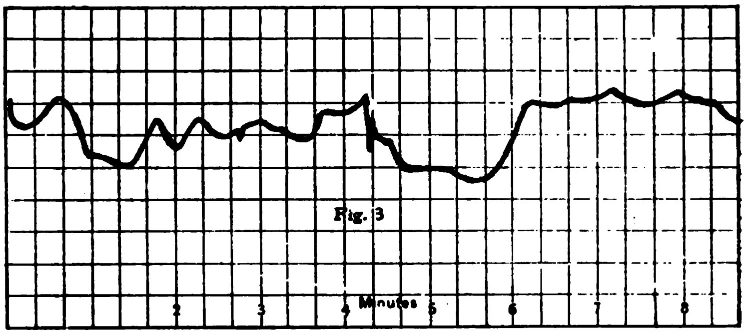


Fig. 3

circuit, and reverses the operation when the potential rises or falls above or below the normal, repeating this performance as often as required. On large generators this regulator operates upon the fields of the exciter instead of on the fields of the main generators.

We have now under consideration the installation of 25-cycle alternating-current generators of large units, to operate synchronous converters for both the street railway and the direct-current lighting systems. This is more complex than the first condition, as the sudden variations of the railway load will have its influence upon the regulation of the generator as well as on the speed of the prime mover. We hope, however, to find a regulator which will maintain an even voltage at the generator terminals under these conditions, and allow us to operate shunt-wound synchronous converters from them and in multiple with our present shunt-wound generators on the direct-current lighting system; also to operate synchronous converters from the same units and in multiple with our present compound-wound, direct-current generators on the railway system, by means of series inductance and compound winding on the rotary fields.

A paper presented at the 182d Meeting of the American Institute of Electrical Engineers, New York, December 18, 1903.

SAFEGUARDS AND REGULATIONS IN OPERATION OF OVERHEAD DISTRIBUTING SYSTEMS.

BY W. C. L. EGLIN.

The distributing system may be considered an integral part of a power-plant and should receive as careful attention as the steam-plant, the hydraulic-plant, or the electrical-plant in the generating station or sub-station. In fact, the distributing system has to meet more severe conditions than any other part of the entire plant, and the safety and reliability of the service depend largely upon the care given to the plant and the selection of material for it.

An overhead distributing system is subject to extreme changes of temperature, extraordinary storms, interference from other lines, interference by building operations, excavations, fires and other casualties, and sometimes a wilful interference by the public (not to overlook the small boy with a stone.) All these varying conditions must be considered in the construction of the line. There are two classes of conditions: first, the mechanical or structural; and, secondly, the electrical features.

The first group will include the study of the territory in which the line is to be run: width of streets, kind of buildings, height of buildings; other distributing systems, possibilities of interference with these systems; amount of power to be transmitted, and whether the system consists of a simple power-transmission circuit, or one complicated with distributing mains covering the larger part of the territory occupied by the transmission system.

Also to be considered are the weather conditions: wind-storms, rain-storms, sleet-storms, snow-storms, lightning-storms, and changes in temperature. The method of erecting the conductors so that they can be properly repaired or additions be made without endangering the lives of the men engaged in this work must be carefully planned. Unless these various points are considered in the construction of the lines, no rules or safeguards for their operation will be of material benefit.

The second group includes the electrical requirements: the conductors, the insulating method of support, and the means provided to take care of any undue disturbances due to lightning or other causes on the line, such as lightning-arresters, fuses, switches, etc.

SPECIFICATIONS FOR MATERIAL TO BE USED.

All of the material entering into the construction of a transmission system should be ordered under specifications which should state clearly the kind of material to be used, and the nature of the tests to which all materials are to be subjected.

The more general requirements are as follows:

Poles.—Poles should be as short as possible to meet the conditions and preferably made of good sound chestnut. Southern cedar or pine poles are sometimes used when chestnut is not obtainable. It may also be necessary to use iron poles under certain conditions. Iron poles are to be avoided, however, principally on account of danger to linemen and also to the short life of the pole, due to rusting. The wooden pole should be roofed at the top to form a right angle, and gained to form a flat of about five inches for attaching the cross-arms.

All poles, upon which are located devices requiring regular inspection, should be provided with steps in order to facilitate this work. Spacing of the poles should be carefully considered and should not exceed from 40 to 45 yards. End- and corner-poles should be braced, and at least every tenth pole throughout the line should be guyed with ¼ or ⅜ inch stranded galvanized wire. Regular inspections, at least yearly, should be made of the condition of the poles; this condition is most readily determined by examination at the base of the pole. When poles are used as junction-poles, that is, when lines are run at right angles and attached to the same pole, special care is necessary. A separate drawing should be made of all such poles, showing the arrangement of the wires—keeping in mind the simplest possible arrangement—as a protection for the men who climb these poles. Switch-boxes, fuses, lightning-arresters or transformers should not be attached to such poles, but on the first pole removed from this junction-pole. Junction-poles can frequently be avoided.

by the use of two poles making a Y connection of the line. By this arrangement the connections are very materially simplified.

Cross-arms.—Cross-arms should be spaced at least 24 inches between centres, the top of the first arm being one foot from the top of the pole.

Braces.—Braces should be made of galvanized iron not less than 1¼ x 3/16 inch thick and about 28 inches long.

Pins.—Pins made of locust wood well-boiled in linseed oil are preferable for voltages of 5,000 volts and under; for higher voltages pins should receive special consideration.

Insulators.—The insulator on the pole line fulfils two functions; namely, the mechanical support of the line, and the insulation. As these conditions vary over a wide range, they must be considered for each condition. This is especially so for voltages of 10,000 volts and over. The two materials of which insulators are usually made are glass and porcelain. The glass insulator is more uniform in quality of material than the porcelain, so that for lower voltages glass insulators are recommended. For higher voltages, porcelain insulators are preferred for the following reasons: greater mechanical strength, better insulating qualities, and greater ability to withstand severe weather conditions.

Insulators for high voltages should be made up of a number of insulators cemented together so as to obtain more uniform insulation and to increase the factor of safety from defective manufacture. Before being used, each insulator for high-tension work should be tested at voltages in excess of the operating voltage.

The method of attaching the conductor to the insulator should be carefully considered; first, to see that the wires can be properly fastened to the insulator; secondly, to see that the strain is transmitted without a twisting or bending strain in the insulator. The only strain permitted should be in compression.

The method of distributing the wires on the pole lines depends on the number and character of the various circuits to be installed. For all voltages below 6,000 volts, the wire should be brought out of the station through long porcelain tubes, properly supported; the various circuits being grouped together but well spaced, and preferably being distributed in a single, or not more than a double row of wires. This fan effect allows the circuit to be distributed to the poles without any undue bunching, thus making each circuit easily distinguishable.

The top gain of all poles should be left vacant so that guard-wires can be placed at any point on the line, should they be required. The transmission circuits which are alive twenty-four hours per day should be placed on the top arm; that is, the trunk-lines should occupy the position where there will be the least liability of coming in contact with the other wires or with the men working on the poles. All other circuits should be placed below, series arc-circuits occupying the lower arms, the distributing series circuit being placed on the house side of the lower arms on outer pin occupied by such circuits. The bottom cross-arm should be used for such secondary circuits or low-tension lines as may be required. Space should always be provided for an extra arm on the pole for the erection of a transformer. Protective devices for each circuit may be classified as follows: circuit-breaker, fuses for branch-circuits, and lightning-arresters. Also indicating instruments as follows: voltmeter, ammeter or wattmeter, and ground-detectors.

In the arrangement of the protective devices, it is desirable to locate as many of these as possible in the station or sub-station, for the reason that they are more readily inspected and kept in perfect working order, which insures the fulfilling of their functions when required. All circuits of 200-kw capacity or over should be protected by means of oil circuit-breakers in preference to fuses, on all voltages over 1,000 volts. These circuit-breakers should be attached to both ends of the line, when two or more feeders are used, and connected to the same bus; and there should be no other circuit-breaker or fuses which are automatic in action placed at any other part of the line. Small branch-circuits may be taken care of when necessary by fuse-boxes, placed upon the first pole of the branch-circuit. These fuse-boxes, however, should be avoided whenever possible. This can be accomplished by making a branch-circuit about the same as the main-circuit, depending entirely upon the circuit-breaker in the station to protect both lines. When small branch-circuits are desired, place such fuse-boxes. These preferably should be an enclosed fuse of the cartridge-type mounted on a porcelain base, the whole enclosed in a fireproof and waterproof compartment. This is usually an iron box with a cover and rubber gasket, clamped so as to make it water-tight.

Lightning-Arresters.—Lightning-arresters should be installed at both ends of the line, in the station and sub-station, on each conductor. Special care should be used in their installation, and provision made that in the event of a breakdown of the lightning-arrester, current may be interrupted by means of a circuit-breaking device.

Series Arc Loop Cut-outs.—These should consist of a mechanically operated switch which closes the circuit at the point of the loop and disconnects the loop from the main line. For the use of constant-potential circuits, there may be either a fuse-box provided with solid catches or fuses depending on the conditions. All of these devices being enclosed in fire and waterproof cases.

Before considering the actions of the safety-devices, it is necessary: first, to examine the faults which may develop and the functions which the safety-devices are required to fulfil. If the condition of a wire parting is first considered, we have first the liability of the wire coming in contact with some of the other circuits; secondly, its liability to fall into the street, and thirdly, its remaining suspended clear of all circuits and the ground.

The first condition: the effect of coming in contact with other wires, would immediately raise the voltage to the more powerful of the two circuits, so it is evident that the insulation of the other circuit must either be as good or there will be a liability of the insulation breaking down at some point on the weaker circuit. This will first be detected at the station by showing that the load is dropped from this circuit; and it demonstrates that the insulation of all circuits must be the same when placed on the same pole-line, unless means are provided to take off extraordinary high voltages. This can be done by placing spark-gaps, which will relieve the high-tension from any low-tension circuits, or by grounding a point on the lower-tension circuits.

Wires falling on the ground will indicate immediately in the station, on the ground-detector, that there is a ground on that circuit; and instructions should be given that as soon as a ground shows on the circuit and the circuit is not carrying the load, to disconnect it.

The third condition will indicate in the station that the load is dropped and will not show a ground. The circuit should be cut off in this case also, and inspectors sent out to look after the trouble.

Fourthly; if a wire breaks and falls, crossing other wires of the same circuit, this will cause a rush of current on constant-potential circuit and immediately open the circuit-breaker. In the series arc-circuit it will cut out a portion of the circuit which will be indicated on the voltmeter, showing the necessity of regular voltmeter readings on such circuits.

Interference with Other Wires Falling or Coming in Contact with the Power-Circuits.—If these wires cross the power-circuit and drop loosely on them, the effect will be to short-circuit the power-circuit on constant-potential circuits; the defect develops immediately. The wires either burn off or an arc may be established which will burn off the power-circuit, breaking the wires and the connection. The provision should be as the conditions shown for the breaking of a wire. A single wire may merely come in contact with one wire of a constant-potential circuit and assume the same voltage as that circuit; there will be no way of determining this at either the station or the sub-station, unless that wire was grounded and the ground indicated on the ground-detectors. In the event of this falling wire coming in contact with both sides of the series arc-circuit, a portion of the circuit will be cut out and indicated on the voltmeter at the station. Should it come in contact with only one wire of the circuit, no indication will be made at the station unless the wire be grounded. For this reason inspection should be made and all such wires changed so as to come below the power-circuit and not above it. This also demonstrates the necessity of placing protective-devices on foreign wires which may come in contact with power-circuits.

Lightning-Storms.—The installing of efficient lightning-arresters as specified may protect the apparatus at both the generating station and sub-station, but fail to protect apparatus at intervening points, particularly the transformers. It is possible that lightning may jump from primary to secondary of transformers during a severe storm. This would be indicated by the primary-fuse blowing in the transformer; and after the blowing of the fuse from this cause, tests should be made of the transformer as follows:

It is essential that when a primary-fuse on a transformer is blown through any cause, the secondaries should be disconnected from the transformer, and the latter tested to full-line voltage between the primary and secondary coils, so as to determine that there is no breakdown in the insulation between these coils.

There are two methods by which these tests may be readily made by the linemen without removing the transformer: first, take from the station a 600-watt transformer, connect its primary for the line-voltage and its secondaries for 100 volts, and connect a 50-volt lamp across the latter. Attach one primary lead of this test-transformer to one secondary wire of the line-transformer, and place one-ampere fuses in the primary cut-outs protecting the line-transformer. Now connect the other primary lead of the test-transformer, first to one and then to the other of the main primary lines. If the 50-volt lamp filament becomes red, the line-transformer is defective, and should be returned to the station. Second method; if impossible to use the first method, proceed as follows: attach a short piece of heavily-insulated rubber wire to one of the secondary wires leading from the transformer. Then place one-ampere fuses in the cut-outs, and connect the specially insulated rubber wire first to one and then the other of the main primary lines. If the fuse blows, or a spark shows when contact is made, the transformer is defective and should be removed from the line.

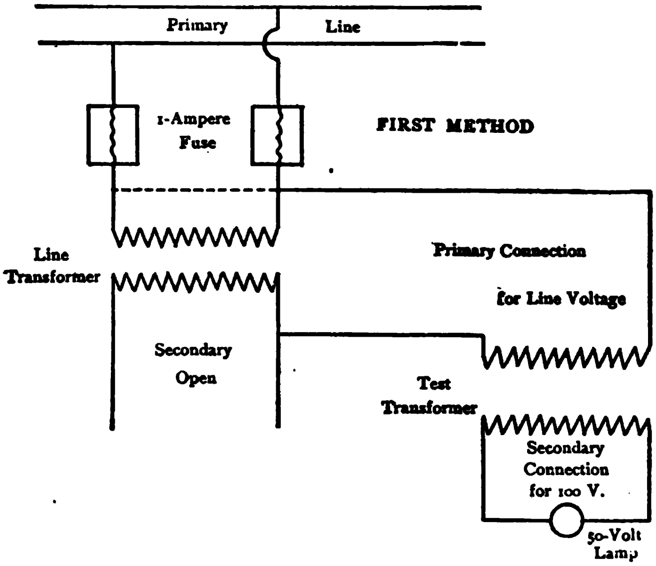


FIG. 1.

In the event of lightning-arresters being placed on the pole line, all such lightning-arresters should be inspected after each heavy lightning-storm.

Transformers.—Transformers when supported on the poles should be hung on an extra cross-arm provided for that purpose. The primary leads from the line to the fuse-box and to the transformer should be insulated with rubber-covered braid, for the line voltage. Transformers should not be attached to buildings or in such locations as to be handled by unauthorized people, and when they are placed in buildings they should be put in a separate fire-proof closet or room which is controlled only by the operating plant. As it is now the general practice to use oil-transformers it is unnecessary to consider dry-transformers. Inspection should be made to see that the cases are properly filled with oil. This should be done by an inspection force, and not by the men erecting the transformers.

Inspection.—The greatest safeguard in a transmission line is regular inspection. Lines can with advantage be inspected daily, not only an inspection from the ground, but a regular monthly inspection of all devices attached to the line when a continued service is desired.

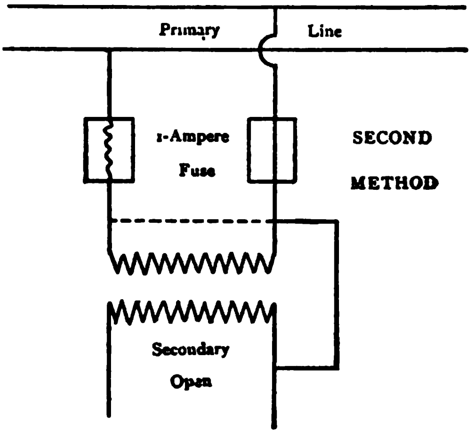


FIG. 2.

It may be necessary on some parts of the line to introduce cable. This should be avoided whenever possible for the reason that the conductors are brought close together at this point and static discharge is liable to puncture the insulation; so means should be provided at both ends of the cable to take care of the static. This is best arranged for by a series of gaps of the lightning-arrester type. Standard lightning-arresters can usually be used for this purpose. They should, however, be provided with a small fuse in series with the connection to the line so as to prevent short circuiting the lines in case of failure of the spark-gaps.

DISCUSSION OF LUKES, BECHTEL, AND EGLIN PAPERS.

H. B. GEAR:—The speaker wishes to emphasize the importance of doing everything possible in the way of providing safeguards on the distributing system to relieve the burden of responsibility now resting upon the central-stations of preserving the continuity of the service. An hour's interruption in a factory employing a number of men may involve great loss to consumer and producer alike.

The development of alternating-current power service in most of our large cities during recent years has served to draw this to the attention of station men very forcibly.

An analysis of reports of line trouble reveals three general classes of accidents which interrupt service; namely, those caused by the blowing of defective or overloaded fuses; those caused by the short circuiting, breaking, or grounding of line wires, and those due to trouble in lightning-arresters and transformers.

Unnecessary blowing of fuses can be practically eliminated by a systematic method of fusing lines according to the connected load, allowing ample reserve capacity in the fuse, and checking up the connected load on all fuses at regular intervals. A set of maps on which the proper size of fuse for each box is marked is of value in this work.

The burning of cross-arms due to the leakage of current from the cases of iron cut-out boxes in wet weather may be reduced to a minimum by mounting these boxes on glass supports. Care should also be used in mounting such boxes on cross-arms not to put them back to back directly opposite each other so that the supporting screws may allow current to pass through the arm and thus burn it. As has been stated by Mr. Eglin, the inability of any form of fuse available for pole-line work successfully to open branches which are fused to carry 50 kilowatts or more makes it advisable to restrict the use of fuses to the branches which are less heavily loaded, depending upon circuit-breakers or station fuses for protection from accidents on feeders or heavily-loaded mains. The main branches should be provided with cut-out boxes, however, for use in testing for trouble.

The duration of an interruption of service is usually short, when the occurrence of trouble on feeder or main operates a device located within the station that can be quickly replaced and is not dependent upon the services of a trouble man.

The majority of interruptions are caused by the second class of accidents and may be diminished by first-class line construction combined with a system of regular inspection by which incipient trouble may be discovered. The importance of a regular inspection of all lines at intervals of one to two months has not been too greatly emphasized.

Interruptions due to burnt-out transformers seem to be unavoidable. The use of lightning-arresters located near the larger transformers is, no doubt, of value in reducing the number of transformers which fail because of lightning, though the entire prevention of this trouble seems to be impossible.

Interruptions due to the burning out of transformers by overloading are very infrequent, it being more often true that the transformer capacity is excessive. Troubles in lightning arresters are undoubtedly diminished by the use of the fuse mentioned by Mr. Eglin, though this would seem to be objectionable from the fact that the fuse might be blown in the early part of a thunder-storm and thus destroy the protection from the remaining discharges of lightning.

The suggestions made by Mr. Lukes, that a standard cross-arm be adopted, should receive general support. A cross-arm similar in dimensions to the one described in Mr. Lukes' paper, except that the distance between the pole-pins is 25 inches, has been in use in Chicago for a number of years with excellent results. Many cross-arms furnished by manufacturers for use on light and power circuits at voltages from 2000 to 4000 are likely to cause trouble, owing to the narrow space between the pins, allowing the wires to swing together in case they become a little slack.

Triple-petticoat, glass insulators, having an outside diameter of about 4.5 inches, have been in use in Chicago on 4000-volt, three-phase circuits for several years with excellent results. There is reason to believe, however, that the deep-groove, double-petticoat insulator, which is used on standard 2000-volt work, would serve the purpose equally well as far as insulation is concerned. The advantage of having a distinctive type of insulator on the higher voltage circuits is such, however, that the triple-petticoat insulator is used on these.

Accidents to linemen working on electric light lines may be prevented in part by regulations requiring the men to use rubber gloves in handling live circuits. Much may be done also in arranging apparatus on the pole in such a way that men can work upon without constant danger of injury.

Danger from fire is practically eliminated when primary wires are kept outside of the buildings and all secondaries, whether two- or three-wire, are grounded. The danger from crosses with telephone wires may be reduced to a minimum by carrying all high-voltage wires above the telephone wires, whether in crossing or paralleling them.

Telephone and lighting wires jointly occupy poles on about 200 miles of pole-line in Chicago, the lighting wires being carried above the telephone wires. Several accidents have befallen life and property due to crosses on these lines, but in nearly every case they have been the result of carelessness on the part of telephone line men engaged in stringing wires. Accidents due to lighting wires falling across telephone wires have been almost unknown.

G. T. Hanchett:—The papers on overhead construction and distributing systems in suburban districts fail to refer to one of the most prolific causes of accidents and troubles on such lines; namely, the grounding of wires on trees. In a suburban town the preservation of the trees in the street is insisted upon. The wires have to pass through the trees and are secured in various ways; but with the growth of the trees the branches come in contact with the wires and produce serious grounds. Limbs six and eight inches in diameter burn completely in two, the limbs dropping on the street, and wires are burned in two by the resulting arcs. The speaker would be glad to hear of any means which will prevent this trouble.

RALPH D. MERSHON:—The first three papers appeal especially to the operating men, and perhaps some one will answer a question in regard to one of the so-called safeguards used in connection with light and power equipments. Why is weather-proof wire used on primary circuits? After it has been up one or two years it is generally in a very ragged condition, or might as well be so far as its insulating properties are concerned, and as a safeguard, in the matter of protecting life at any rate, it is then worse than useless because it engenders a false confidence.

CALVERT TOWNLEY:—An experiment was made on a railroad in western Pennsylvania some time ago, whereby it was sought to determine how many lightning-arresters. should be used. A lightning-arrester with suitable ground-connection was installed on every pole for several miles, great care being taken to see that the installation was properly made. Tissue paper was then placed in each arrester in such position that it would be punctured if a static discharge passed through that piece of apparatus, and after every storm these papers were inspected. It was found that four arresters to each mile of conductor carried off all static disturbances which occurred through numerous and severe thunder-storms; indicating that with such a number the tendency for a discharge to escape by any other means than through the arrester was extremely remote.

The fact had been brought to his attention that many operating companies while exercising due diligence in the inspection of the main parts of their system neglected to inspect properly the lightning-protection devices, resulting in defective ground connections, undue bends in lightning-arrester wiring or other defects which rendered the arrester ineffective. This is a question which is of relative greater importance to the smaller electric light installations than to power-transmission lines, but it has not been given the attention it deserves.

P. M. LINCOLN:—In Mr. Eglin's paper, on page 749, under the head of "Pins," it is said: "The pins should be made of locust wood well-boiled in linseed oil, and are preferable for voltages of 5000 volts and under." If the treatment recommended is for the purpose of preserving the pins, no criticism is offered. If, however, the treatment is meant for the purpose of making insulators of the pins, issue must be taken with that statement. The speaker believes thoroughly in treating the insulator as the only insulation of the line and to rely entirely on the insulator as the only insulation. It has been noted, particularly on the high-pressure lines, that under certain conditions there is a considerable burning of the pins, particularly if the insulators become coated with dust. There are two ways to remedy that difficulty—one to make the pin a perfect insulator and keep it so, and the other to make it a conductor. You cannot very well make the pin a perfect insulator and keep it so unless you put it in a glass case, and that is a little difficult. It seems that the other method is the logical one to pursue; that is, to make the pin a fairly good conductor, so that the escaping current cannot generate sufficient heat to cause this burning.

M. P. RYDER:—Experience with overhead ines has shown that it is not safe to depend upon the insulation of the wire, whether it is rubber of the best quality, or ordinary weather-proof. Weather-proof insulation is a good protection in dry weather, saving a great deal of trouble that would occur without it. In many cases where wires become crossed, or are thrown together in handling, the weather-proof insulation has prevented short-circuits. (This refers to alternating circuits of 2500 volts or less.)

Regarding lightning-arresters, the speaker has found none that will give complete protection., Lightning does some queer things that cannot be accounted for by any of the accepted theories. Nothing is gained by using a great number of arresters. The greater part of the trouble from lightning occurs at the extreme ends of the circuit. If good arresters are installed at the station, and at the outer ends of the circuits, they will furnish about all the protection necessary.

Why does lightning cause the primary fuses of a transformer to blow without causing any injury to the transformer? Many cases of this kind, both with oil-filled and dry transformers are known. When the fuses are replaced the transformer will go on with its work as though nothing had happened.

GEORGE F. SEVER:—In Mr. Lukes' and Mr. Eglin's papers there is mentioned the possible crossing of telephone and signal with high-tension wires. This is an extremely important point to electrical engineers of municipalities. In the daily papers of December 16th, 1903, there was recorded the fact that at Joliet, Illinois, a feed wire of the Joliet Electric Railway carrying current at 16 000 volts, broke and fell across a Western Union Telegraph Company's wire causing fires in buildings, in some cases 19 miles distant. It is absolutely essential to eliminate such an occurrence through good engineering practice.

M. P. RYDER:—Regarding the rules of the Underwriters for the building of high-pressure lines: Some of their requirements are not practicable; for instance, the placing of a grounded network under the high-tension circuit having a conductivity equal to that of the circuit. In a great many cases this would require very heavy construction, so heavy that it would not be practicable to put it on the poles. As a matter of fact, it is very seldom that an electric light or power wire breaks down. A wire of larger size than No. 6 will stand up under sleet, or almost any other storm that occurs in this climate. The proper way to protect low-tension wires is to place them below the high-tension wires.

H. G. STOTT:—Some years ago a Committee of the INSTITUTE met with the Board of Fire Underwriters and a rule was passed making it permissible to ground the neutral at the central point of the transformer, or at one side of the transformer. The grounding of any part of the secondary network, especially the neutral point, is the best form of protection obtainable, because in case of a cross with an electric light wire, carrying perhaps 8000 volts, the pressure of the wire is immediately reduced to the pressure of the circuit, as the carrying capacity of the secondary network is greatly in excess of the amount of current passing through the average arc-light circuit. Then grounding is also a good protection from lightning, because when lightning strikes the high-pressure line the oil transformer forms one of the best lightning protectors. It is a very common occurrence, as one of the gentlemen remarked, for the primary fuse to blow on a transformer in a lightning-storm. This is caused by the current jumping across either between the turns of the transformer and short-circuiting the transformer, or, if the secondary is grounded, jumping through the insulation to that ground. Then automatic apparatus at the power-house ought immediately to cut out that circuit; on replacing the circuit-breaker in the power-house, in nine cases out of ten, the line will be perfectly clear as the oil will have sealed the fault.

It is well to emphasize what has been said in some of the papers to-night that all automatic apparatus should be concentrated in the power-house or substations. It is very well to have some means of breaking up the overhead lines into sections, to have a well-designed oil switch of small dimensions which can be mounted on the poles, so breaking up the line into different sections, so as to render it easy to test and cut out different sections in locating trouble—these things are valuable auxiliaries to engineers who handle overhead service. The question of grounding the neutral is an important one, more especially for the protection of life in possible crosses with higher pressure circuits which must inevitably occur sooner or later in all overhead circuits.

W. C. L. EGLIN:—The interference with overhead wires by trees is frequently a source of trouble. There has been a number of methods suggested in connection with the construction of lines through trees. The so-called tree insulator is a porcelain insulator attached to a limb of a tree, or a long wooden insulator attached to the conductor. Neither of these devices is satisfactory on account of: first, the swinging of the limbs of the tree; and secondly, the movement of the conductor, owing to the expansion and contraction of the limb. An insulator attached to a conductor will not have a fixed position, so that any device of this kind must be considered merely temporary. Specially-insulated conductors have been used in which a heavy rubber insulation was protected by means of a flat steel armor band wound spirally around the insulation. It was thought that the armor would prevent the chafing of the insulation against the limbs of the trees; and the armor would cut the limbs, instead of the limb wearing away the insulating material. Experience with this form of conductor has not been satisfactory, as the insulation frequently breaks down between the armor and the conductor, and there is no easy method of detecting such a fault.

The author agrees with the criticisms of Mr. Mershon and others that weather-proof insulation is of no value as insulation for the line; and as previously stated, the insulation should be provided for by the insulator, and that pins, cross-arms and other material are formed by part of the structural features of the line. He has attempted to emphasize that the insulator is the part which should receive attention as far as the degree of insulating is required for the line.

The author differs with the view expressed in the question of gloves for the linemen, and is of the opinion that the use of rubber gloves should be prohibited, for the reason that men depend on gloves and take unnecessary risks, assuming that they are properly protected when using them. There is difficulty in having the gloves returned for inspection, but even with the best care the glove, to be of any value as an insulator, should be very much heavier than it is practicable to use. The other objection; although gloves may offer some slight protection to the hands, there are other parts of the body exposed and through which a man may receive a fatal shock. It is better to arrange the various devices that must be handled so that they can be cut out or grounded while being worked upon. An example of this would be a series arc lamp on an iron pole. This lamp might become dangerous owing to the circuit being crossed with some foreign circuit when not in use, and while the trimmers are trimming the lamps. The method of rendering this safe is first to ground the circuit at the station, which is easily done; and further, have a ground connection attached to the iron pole by means of a flexible cable and a hook which can readily be attached to the lamp, thus rendering the trimmer free from any liability of receiving a shock.

The principal reason for placing lightning-arresters in the stations is that they can be inspected and kept more frequently in operative condition. Some circuits of about thirty miles in length have shown continuous discharge, during a lightning-storm, at the station. There are undoubtedly locations where it would be advantageous to place lightning-arresters on the lines. The location of lightning-arresters, however, is a question which has to be studied for each particular locality, and the speaker does not believe there is any fixed rule for the installation of lightning arresters on distributing systems.

Ralph D. Mershon:—The speaker is glad to hear the unqualifi- condemnation of weather-proof wire. In a number of cases, where he has been connected with the installation of power and lighting plants, he has tried to get away from weather-proof wire and put in bare wire. He is also glad to hear what Mr. Eglin says in regard to rubber gloves, as it agrees with his ideas. The speaker has ordinarily been concerned with voltages where rubber gloves are of no value under any conditions, but believes they are ordinarily a source of danger rather than safety. Dependence is put upon them; and although they should be tested from time to time, they are not, and the result is that some one is killed. A man working with his bare hands will take care that the conditions of the work are safe, and such care is better than dependence upon rubber gloves.

H. B. Gear:—There is one important point regarding the use of weather-proof wire which has not been mentioned. In cases where accidents have occurred to employes or citizens, the question of the insulation of the wire from which the injury was received is the first one to arise. If witnesses can be put on the stand to say that the wire was insulated, the company is placed in a far better position before the jury than it would be were bare wire used.

Weather-proof insulation, while it may not be an insulation of great value as a protection for crossed wires in wet weather, is unquestionably of considerable value in dry weather until it becomes so old that the outer braids begin to shred off and become brittle. When it reaches this condition there is but one thing to do and that is to replace the wire.

Weather-proof insulation is of value as a protection to linemen who may be at work on the poles while the circuits are alive, since it protects them from injury which might be caused by momentary contact with 2000 volt circuits, were weather-proof wire not used. Weather-proof insulation will remain in fairly safe condition for five years or more.

The speaker agrees with Mr. Ryder that it would be quite impracticable to put up a protecting network which would be required on lines carrying a large amount of energy. There are a great many places in cities where it would be physically impossible to comply with the requirements affecting the distance between poles and buildings, for the reason that where pole lines are run in the street the distance from buildings is necessarily limited. The strict enforcement of some sections of these rules would prevent the erection and maintenance of high-tension pole lines within the limits of cities.

As to lightning protection, the experiments which have been described this evening show that the average distance between points at which discharges take place is about a quarter of a mile. It has been the practice in Chicago to install arresters at about these intervals, but it has been observed that not infrequently transformers of the old type of first-class manufacture have been burned out by lightning in locations from 300 to 500 feet distant from the lightning-arrester.

[COMMUNICATED AFTER ADJOURNMENT. DISCUSSING "AUTOMATIC APPARATUS FOR REGULATING GENERATOR AND FEEDER POTENTIALS." BY A. C. PRATT.]

Several types of pressure regulators, designed to control either the generator field or the exciter field, have as their primary element a solenoid actuated by the potential of the system which it is desired to control; and in some cases further actuated by a current in a separate winding on the same solenoid, from a series transformer in one leg of the main system, designed to compensate for I^2R line losses; but no attempt seems to have been made to compensate also for line drops, due to varying power-factor.

Suppose a fairly long high-pressure transmission system to require 15 amperes charging current. Then 15 amperes at the generating station might represent either no load, or from one-fourth to one-half normal full load at the consumer's end. The common type of regulator, with compensating solenoid as above, might be expected to maintain nearly the same potential at the generating station for the 15 amperes charging as for 15 amperes work-current, but with a wide variation in the potenital at the consumer's end of the line. If, however, the current in the potential winding of the solenoid be given a lag relative to that in the current winding, of perhaps 60° or 70° for load at 100% power-factor, then the percentage compensation, due to the series-current winding, will vary with the power-factor. This lag in the potential winding may be produced by tapping from another phase of a three-phase system, or by a combination of inductance and resistance, in series with the potential winding, or both; the latter expedient allowing ready means of adjustment of the angle of lag by varying the inductance and resistance.

The writer has found that with about the above conditions in the controlling solenoid, the potential at the consumer's end of the line could be maintained nearly, though not quite constant, while the current at the generating station varies from 20° leading to 50° lagging, and from full load to no load.

DISCUSSION ON LUKES, BECHTEL, AND EGLIN PAPERS AT PITTSBURG, JANUARY 7, 1904.

C. F. SCOTT:—The evolution in electric apparatus and systems has been along two different lines; the work outside of the station, such as the general system and external construction, has proceeded along quite different lines from the development of the apparatus within the station. The latter—the dynamos and switchboards, including the design of the apparatus and the methods of its construction—has been handled almost entirely by manufacturing companies. The engineers of these companies have developed the dynamos, the switchboards, the safety devices, the methods for operating within the station, and they have become expert in this work. There has been a wholesome rivalry, intensified by commercial competition, which has led to a constant endeavor to produce the best apparatus, and to develop new forms to meet new requirements.

Outside the station, however, there have not been a few concentrated sources of development, but in a way each situation has been left to work out its own salvation. Some companies, notably those in large cities, have placed their problems in the hands of able engineers, who have worked out the best distributing systems for their particular conditions. The problems of pole construction, transformer mounting, arrangement of safety devices for cutting out circuits in cases of emergency, the general arrangement of feeder systems, the problems encountered in going over or under rivers, and various problems, both in overhead and underground circuits, have been worked out more or less satisfactorily to meet the varying local conditions. In many cases these problems have been relegated to the enterprising linemen and the results justify the conclusion that no particular engineering ability or theoretical knowledge has been exercised. As a result, the problems external to the station, generally speaking, have not been worked out as satisfactorily as those within the station. The use of high pressures has increased more rapidly than the ability to handle them properly. Circuits for 20 000 or 30 000 volts are sometimes found which have been put up by men who are accustomed to 500 or 1000 volt circuits and who do not know the differences between 2000 and 20 000 volts.

An engineer recently told the author that he had inspected the apparatus in a number of synchronous converter sub-stations. He found sub-stations receiving 20 000 volts, which were wooden structures with oil-insulated transformers in the basement covered by a wooden floor. An accidental short-circuit in wiring or transformers could scarcely occur without resulting in the destruction of the whole station.

Papers, such as these which have been presented this evening, have their chief value in making public for the use of many others the results which have been obtained through the efforts of the able engineers of large companies. It is these details which are essential to the successful operation of electric power and lighting plants.

S. P. GRACE:—In looking over the various power transmission plants built during the past ten years, there will be seen evidence that the machinery has been carefully designed and constructed to meet the exacting requirements of high-pressure transmission. The work of the trained technical engineer is everywhere apparent.

But when the aerial lines for the transmission of the high-pressure current are examined the widest divergence of practice will be found. Many times this part of the plant has been turned over to a line foreman with orders to design and build it. The result has been a line fairly well suited for low-pressure lighting circuits, but hardly appropriate for the transmission, at high pressures, of thousands of horse-power of electrical energy. This criticism can be particularly made in city districts where, to supply outlying boroughs, the pressure has been gradually raised.

A line to carry a pressure of more than 10 000 volts should be most carefully designed and rigidly constructed, so that the danger to life and property will be minimized. It is hopeful to note that this is being realized by the power interests, and strong heavy transmission lines are now the rule where formerly they were the exception. No matter how strongly these lines are built, they will at times fail, and the falling of their wires on low-pressure electric light, telegraph, and telephone wires may cause disastrous consequences. The futility of trying to protect low-pressure circuits, by means of fuses, from high-pressure crosses is well known. A 10 000-volt current has little respect for the ordinary telegraph or telephone protector. Means must therefore be provided to prevent the high-pressure wires from coming in contact with the low-pressure wires. To protect its telephone wires one company proposes to insist on the following rules:

1. That the high-pressure line must never be so constructed that its wires will be parallel to, and either above or below the telephone wires.
2. That where, of necessity, a crossing must occur, it be made as nearly as possible at right angles.
3. That the high-pressure wires pass over the telephone wires with not less than 10 feet clearance. In exceptional cases the high-pressure wires may pass under with 10 feet clearance.
4. That guard-wires be provided at all crossings with high-pressure wires carrying more than 5000 volts.
5. That both lines be strongly head- and side-guyed at the crossings.
6. That the power company stand the expense of the necessary protection.

Where the telephone line is underneath, the guard-wires will consist of a grounded strand placed between the tops of the telephone poles and a network of insulated wires suspended from a 16-foot cross-arm.

The telephone wires at the crossing will be lowered three arms to provide space for the guard-arm, or if this is impossible, an extension-fixture will be used.

The steel-strand rope, suspended from the tops of the telephone poles, will be led down the sides of the poles and grounded in several bushels of coke. This strand will be proportioned to the size of the wires in the transmission line, and it is expected that they will be quickly burned off when they come in contact with the grounded strand. In addition to the grounded strand, there will be placed about 30 inches below it, six No. 6 iron guard-wires, suspended from two four by five inch 16-foot guard-arms, equipped with high-pressure insulators. These wires are momentarily to protect the telephone wires before the power-wires have had a chance to settle on the grounded strand. If, from some unforseen cause, the grounded strand should be burned in two, the guard-wires, being attached to high-pressure insulators, offer a protection to the telephone wires underneath. With this double protection it is felt that the power-wires can do but little damage to the telephone system. Where, of necessity, the power-line is underneath, a similar system of protection will be used. However, the guard-wires will be suspended from the poles of the power-line, since the guard-wires should always be placed at right-angles to the wires liable to fall. The strand wire, in this instance, is not grounded, since its principal function now is to hold up the weight of a large number of telephone wires, which might simultaneously fall on the power-line. The guard-wires underneath are simply for the purpose of holding the telephone wires away from the power-wires and therefore do not need to be insulated. They may be wrapped around the guard-arm. The power companies are willing and anxious to protect the telephone lines, and agreeable to bearing the expense of their protection. With the exercise of proper care, but very few accidents should be caused from high-pressure wires.

DISCUSSION ON BECHTEL PAPER, MINNEAPOLIS, JAN. 8, 1904.

C. H. **CHALMERS**:—The ordinary guarantees of regulation of generators, such as six per cent increase on pressure of non inductive and 10% on load with 80% power-factor, mean practically no regulation. A proper specification for pressure regulation should include a pressure regulator guaranteed to keep the pressure within one per cent of normal for speed variations of five per cent from normal, either way, for a variation of power-factor from unity to 75%, for variations of load from zero to 50% overload, and for changes of temperature of the generator from that of the room to 55° Centigrade above the room temperature; and this regulation should be obtained when any or all of these causes of variation exist simultaneously. There are four principal sources causing variations of pressure, as follows: variation in speed, in the load, in the power-factor of the load, and in the changes of temperature. A pressure regulator external to the generator actuated by variation in pressure alone is a perfect remedy for variations due to any or all of these sources, and moreover permits the use of the very simplest form of generator, eliminating series coils and all apparatus for compensating pressure changes.

GEORGE D. **SHEPARDSON**:—Automatic regulators ordinarily cause as much trouble as they are supposed to eliminate; they have usually been untrustworthy, and it is as necessary to have an attendant to watch the regulator as it would be to watch the pressure changes themselves; there is practically no saving in attendance. Moreover, as long as central stations charge for energy and not for light, there is little direct incentive to them to give the best regulation, since their income is not increased thereby. The interest of the central station man is rather to use all low efficiency lamps and the consequent sale of a greater amount of energy for a given amount of light.

A paper presented at the 182d Meeting of the American Institute of Electrical Engineers, New York, December 18, 1903.

GAS POWER FOR CENTRAL STATIONS.

THE ADVANTAGES OF OPERATING ELECTRIC STATIONS IN CONNECTION WITH GAS WORKS.

BY J. R. BIBBINS.

At the present time two competitors of the reciprocating steam-engine—the steam-turbine and the gas-engine—are attracting wide attention. Engineers, particularly, are interested. Heretofore the interest taken in gas-engine plants seems to have been confined chiefly to those operating in foreign countries, but as there are a number of successful installations of this kind in the United States, it may be of interest to present a few facts about their operation. It is intended in the following pages to offer testimony upon four contentions, viz.:

A. That present gas-power machinery is suitable for central-station service.

B. That a well-equipped gas-power electric-plant can operate with far better economy than a steam-plant under similar conditions.

C. That its operation is much simpler and requires less running expense for the same results.

D. That gas works, laboring under low load or output-factor, can profitably install a gas-power electric generating station, and become its own largest customer, selling both gas and electricity at competitive rates.

The basis of this paper consists of data collected from various electric-light and power-plants in the United States using gas-engines as their principal motive power. A number of these plants being operated in connection with illuminating-gas works, it has been possible to observe the somewhat unique position of the gas-engine station as a direct though affiliated competitor of the gas works.

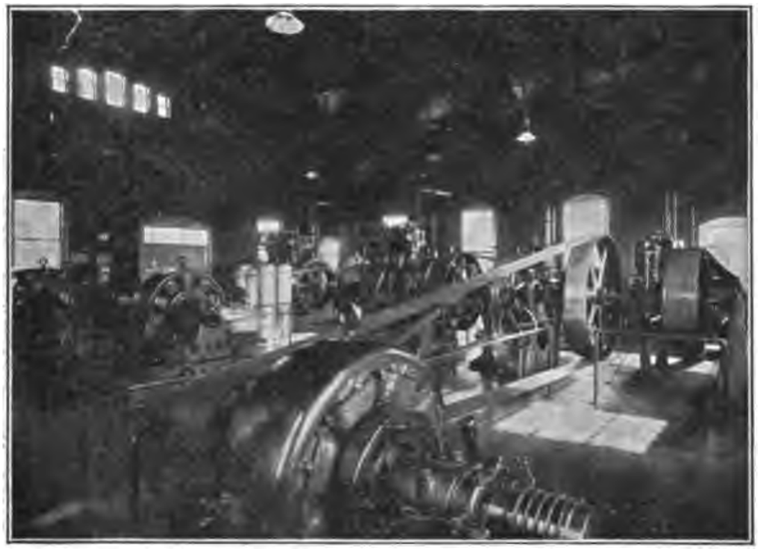
TABLE I.—GAS-POWER PLANT EQUIPMENT.

Plant No.	Engines.					Generators.				
	Rated Capacity Full Load. b.h.p.	No.	b.h.p.	Transmission.		Incandescent Power.	Railway.	Arc.	Total kw. Generating capacity.	* b.h.p. Gen. / b.h.p. Eng.
				Character.	Efficiency.					
1	685	3	125–280	Belt.	82.5	1-phase.	550 V. D.C.	..	370	.845 (*a*)
2	170	2	85	"	80	....	..	230 lts.	112	1.00 (*b*)
3	110	2	55–	Jack-shaft	75	2-phase.	..	..	75	1.2
4	90	2	35–55	Belt.	80	1- "	..	..	40	0 93
5	320	4	55–125	Jack-shaft	75	3- "	..	60 lts.	232	1.18 (*c*
6	360	4	55–125	"	75	2- "	..	..	215	1.14
7	305	3	55–125	Belt.	82.5	1- "	..	..	260	1.38
8	280	1	280	"	80	1- "	..	50 lts.	152	0.91
9	140	2	55–85	"	..	1- "	..	..	100	0.96
10	85	1	85	'	80	1- "	..	..	60	1.17
11	803	6	125–210	"	82.5	1- "	..	200 lts.	476	0.97 (*d*)
12	255	(*x*) 3	85	'	80	2- "		..	116	0.78 (*e*)
13	375	3	125	Direct-connected	85	2 – .	..	..	225	0.94 (*f*)
14	500	4	125	"	85	2 – .	..	..	300	0.96 (*f*)
15	840	3	280	"	85	2 – .	..	..	450	0.85 (*f*)

(*) e.h.p. at engine shaft.
(*a*) Largely railway load—running 15–18 hr. per day.
(*b*) Exclusively arc.
(*c*) Monocyclic system—runs 24 hr. per day.
(*d*) Plants operate 24 hr. per day—Natural-gas.
(*e*) Natural-gas.
(*f*) Operates in parallel—Natural-gas.
(*x*) 8-h.p. engine belted to air compressor and pump.
(ϕ) Phase.

Equipment.—Table 1 presents the most important data upon the general equipment and service rendered by the first twelve plants considered. The identity of the plants is withheld, in most cases by request, thus making available more complete and valuable data. These plants are located in centers ranging from 2000 to 20 000 inhabitants, and, in most cases, where the cost of fuel is high. The equipments average about 300 brake horse power capacity and operate every standard form of generator for arc and incandescent lighting and for railway or general power service. All the generators are belted, the majority directly, but a few through the medium of a jack-shaft, the latter arrangement being employed in order to obtain the desired flexibility of service without installing a number of engines of small size.

Plants 13 to 15 are somewhat larger and generate polyphase power for industrial works. These three plants average approximately 570 brake horse power and the units are all direct-connected and run in parallel. Results of operation have been obtained from plants 1 to 11 inclusive, the first and last furnishing excellent data upon the comparative economy of the present gas-engines and the steam-engines which were replaced.



Typical Belted Station, with Jack-shaft.

In general, the character of electrical equipment is not all that could be desired for furnishing results of great accuracy; but owing to the more or less uncertain calorific value of the fuel-gas used, errors of a few per cent. in particular cases will not have much effect upon the general result. In any event, the average cost of power charged against the station is the desired figure.

Service Requirements.—In considering the subject in hand from an unbiased standpoint, it is important to enumerate the qualifications imposed upon the gas-engine, in order to determine its actual merits.

1. Continuity of service at any cost.

2. Simplicity of operation, conducing to the above and securing low cost of attendance.

3. Reasonable cost of equipment.

4. Economy of fuel and supplies.

1. A 65-h.p, two-cylinder vertical engine of the type employed in the plants here considered has made the following record:

Load	Fan Blower.	
Total elapsed time	8472 Hours.	100.0%
Hours run	8230 Hours.	97.0%

HOURS SHUT DOWN.

Changing igniters	38 Hours.	0.45%		
Taking up bearings	13 "	0.15%		
Painting	179 "			
Repairing blower	5 "			
Changing gas supply	7 "			
Total	—		242 Hours.	3.0%
Ditto chargeable to engine				0.6%

During this period the engine ran, without stopping, 1157 hours and was then shut down to repair a broken belt.

In a pumping station located on the Allegheny, a short distance from Pittsburg, five 85-h.p. engines of the same type operate regularly at full load through the week without stopping, except on Sunday, when the units are shut down in rotation for inspection and repair. Each engine operates from 96 to 98% of elapsed time. It is needless to state that such service would not be required in central-stations, as reserve-capacity should be available for use during peak-loads. In the present exhibit, the majority of the plants operate from 18 to 22 hours per day, giving ample time for inspection and repair, even if no reserve-capacity were provided.

2. The skill required for operating a gas-plant is apparently no greater than for a steam-plant. In several instances where the latter have been replaced, the old employees have been retained. In newly-established plants steam engineers have invariably taken charge after short preliminary instruction from the builders' erecting engineer.

In plant No. 11, weekly inspection of bearings, igniters, and valves were at first carried out. This was found to be unnecessarily frequent and is now done once a month. The cylinders are inspected occasionally throughout the year. This plant, 800-h.p. capacity, is operated by three day men and one night man, ten hours to a shift. The former steam-plant, about 500-h.p. capacity, required two day men and one night man, 12 hours to a shift.

3. In cost. the gas-engine equipment is quite comparable with that of a steam plant. The engine itself costs more than a steam-engine of corresponding size, on account of the increase in metal required by the higher pressures dealt with. With the cost of condensing machinery charged to the steam-engine, however, this disparity is much reduced. With natural- or illuminating-gas supply available, the cost of equipment would fall considerably below that of a steam equipment of boilers, engines, condensers, heaters, pumps, etc. In the case of a producer-gas plant installed to supply the gas-engines, the cost of the respective equipments, each of 1000-h.p., is nearly at a parity, depending somewhat upon the gas-storage capacity provided. This, however, amounts to much less than electric storage. For producer-gas the former costs in the neighborhood of $7.35[1] per h.p. and the latter $100. Considering the increase in productiveness of labor, which is stated by a prominent gas-engineer to be

Typical Belted Station

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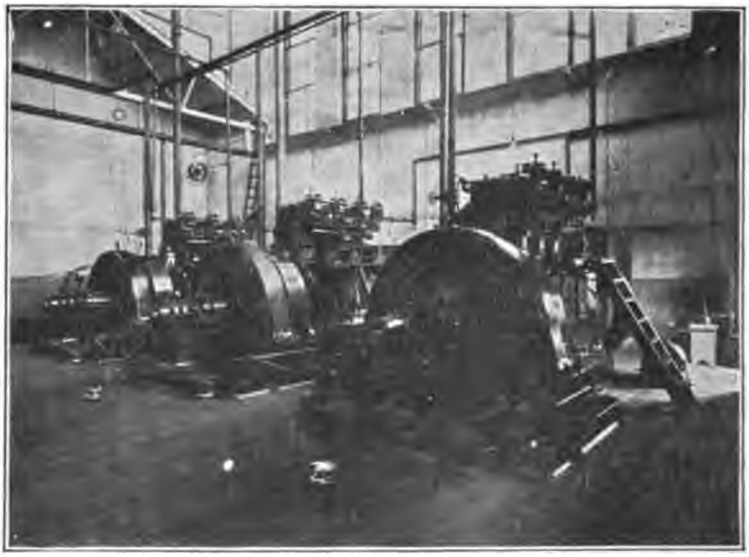
[1] $100 per 1000 cu. ft.

fully 100% (owing to the fact that one man can handle twice the amount of coal), the advantage, if any, held by the steam-plant, disappears.

4. In economy of fuel, the gas-engine admittedly has no rival. The present limit of steam-engine practice is 10 lb. water per i.h.p, or 11 lb. per b.h.p. With an evaporation of 10 lb. of water per lb. of good coal (14 000 B.t.u. per lb.) a performance of 1.1 lb. coal, or 15 400 B.t.u. per b.h.p. is realized. The gas-engine at present delivers, at full load, a b.h.p. upon 10.5 to 11 ft. of gas (of 900 to 1000 B.t.u. per cu. ft. calorific value) which is equivalent to 10 000 to 11 000 B.t.u. per b.h.p.; the Fig. on page 773 shows a typical test-log upon a 550-h.p. engine of the three-cylinder vertical type, employing the four-stroke cycle. The thermal efficiency shown is the true or " kinetic " efficiency, viz.:



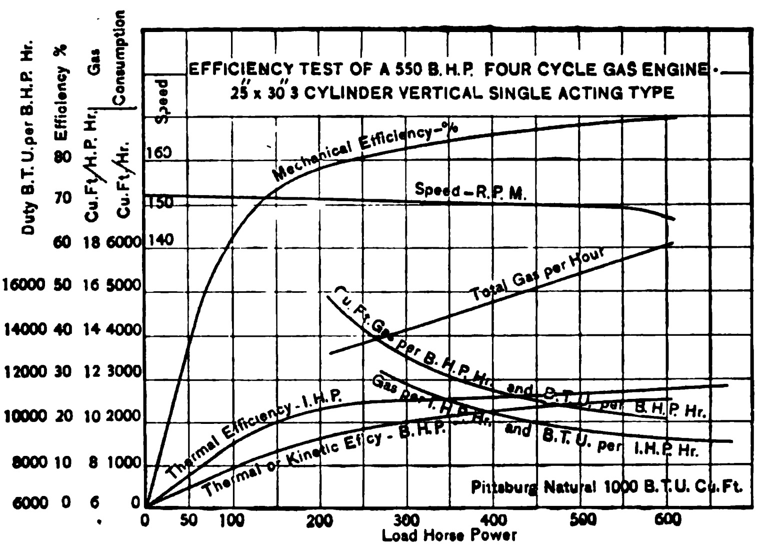
Typical Direct-Connected Station.

$$\frac{\text{Output}}{\text{Input}} = \frac{\text{B.t.u. equivalent of work done}}{\text{B.t.u. value of gas}}$$

At full load this appears as 25%. Considering the comparative remoteness of the theoretical limit of gas-engine efficiency, and the fact that the theoretical efficiency of a steam-engine working between the usual units of 150 lb. boiler and 3 lb. condenser-pressure has already been exceeded, there appears to be an encouraging future for internal combustion motors.

Advantages.—The advantages of the gas-engine for central-stations may be summarized thus:

1. Minimum fuel and heat consumption.
2. Light load efficiency higher than steam-engine of corresponding size.
3. Low cost of operation and maintenance.
4. Simplification of equipment.
5. Small number of auxiliaries required.
6. Absence of " standby " losses.



7. Quick starting.
8. Waste heat in jacket-water suitable for building heating.
9. Ease of extending equipment.
10. Absence of high-pressure except in engine-cylinder. No danger from explosion outside, as a mixture of proper proportions is required.
11. Power can be stored during light loads at small cost in the form of gas in holder.
12. Subdivision of units more easily accomplished, yielding higher all-day economy.

An important source of economy in gas-plants is the fact that as soon as an engine is shut down, all heat-losses cease. Also, during operation no heat is lost by the gas in transit from the producer, and the plant is not hampered by inefficient auxiliaries such as steam-pumps, condensers, return-traps, etc., all of which largely increase the general complexity of the system. Steam-pipe and cylinder-condensation losses, radiation, leakage in piping and fuel-loss in banking fires, have no parallel in the gas-plant. The only auxiliaries required are the igniter-generators, and air-compressors. The former are negligible as affecting the economy of the station, and the latter operate at full capacity at regular intervals. In cases where artesian wells supply jacket-water, a pump is of course required, preferably operated by a motor or small gas-engine to which the air-compressor may also be belted.

In quick starting, the gas-engine fulfils every requirement. The 280-h.p. pumping units of the Philadelphia high-pressure fire system have been repeatedly started cold, brought up to speed, and the pumps loaded to the required pressure (300 lb. per sq. in.) within a period of 40 seconds from the starting signal. In plant No. 11, employing 133-cycle high-speed belted generators, the units are regularly started in two minutes, and this may be reduced to one minute in case of necessity.

A number of plants make use of hot jacket-water for heating the office building, ordinary cast-iron or coil-pipe radiators being used for this purpose. One station partly supplies a municipal heating system resembling the Yaryan, thereby deriving direct revenue from a waste product. Part of the return-water is sent again through the jackets, the temperature being lowered to the proper degree by adding fresh water from the station supply-main. Station No. 14 returns hot jacket-water to a large cistern where it partially cools and is again pumped through the jackets emerging at a temperature of 200° fahr., before being discharged into the sewer. As return water from a heating system is also discharged into this well, a small amount of cold water from artesian well or city water system is added from time to time to reduce the general temperature of the circulating system. In another plant, the jacket-water is utilized in winter for warming the water in the gas holders to prevent freezing. This was formerly done by using live steam from a boiler used in making water-gas. It is estimated by the manager that a saving of $250 per year is effected. In locations where water is expensive, a small cooling tower may profitably be installed to cool the jacket-water which may then be saved.

In the matter of parallel operation of alternating-current generators, plants 13, 14, and 15 have been distinctly successful, particularly in view of the variable character of load incidental to large industrial works operated by induction motors. All the units are of the direct-connected type with standard flywheels. A spring-coupling provides a flexible connection between engine and generator, to absorb cyclical speed variations. The usual copper dampers on the pole pieces assist in preventing hunting. In general, a low frequency seems to be desirable, with high peripheral speed and moderate reactance in the generator to assist in damping current fluctuations. The suddenness of the impulse in a gas-engine cylinder offers, to be sure, greater difficulties than in the case of a steam-engine, but the remedy has apparently been found.

Fuel Gas.—Several distinct fuel-gases suitable for gas-engine use are available. When reduced to calorific values per foot of explosive mixture of proper constituency, the ratings are nearly equal:

	Approximate B.t.u. per cu. ft.	
	Gas.	Mixture *
1. Natural-gas	1000	91.0
2. Coal-gas	650	91.7
3. Water-gas	300	88.0
4. Carburetted water-gas	600	92.0
5. Producer-gas	120 to 145	60 to 68
6. Coke-oven gas	600	90.0
7. Blast-furnace gas	90	53.0

The power to be developed by an engine of given proportions does not therefore vary within appreciable limits, except on producer-gas and blast-furnace gas when larger engines are required, or larger cylinders on the same engine frames. The rate of combustion is less rapid with these than with other gases, due to the large amount of inert gases such as N and CO_2 present in the mixture. The compression may, however, be carried much higher without risk of pre-ignition or "back-firing," thus increasing the efficiency of the cycle. With water-gas the high percentage of hydrogen occasions quicker combustion and higher flame temperatures with so considerable a tendency to pre-ignition and back-firing that this gas is not well adapted to gas-engine work.

In water-gas plants a great saving may be made and the gas rendered much more suitable for the operation of gas-engines

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*A. M. Gow, Eng'rs. Soc., West Penna.

by providing additional holders for the air or blast-gas made during the period when the producers are under blast. This gas is equivalent in calorific value to blast-furnace gas—90 B.t.u. per cu. ft.—and is generally allowed to go to waste. It may, however, be used to great advantage for power purposes, either alone or mixed with a proportion of water-gas which it renders less snappy and thereby better suited for use in gas engines. In fact, by this means a gas is obtained similar in many respects to the producer-gases made by operating a producer continuously with combined steam-and air-blasts.

Leaving out of consideration the by-product, or waste coke-oven and blast-furnace gases, as occupying a field of power-development somewhat foreign to the subject in hand, producer gas offers at present the greatest possibilities in the field of power for use in manufacturing centers. This is due to its comparative cheapness, simplicity of installation and general efficinecy when gas for power purposes is alone considered.

A comparison of the approximate thermal efficiencies of the various processes gives the following results:

Coal-gas (without coke)	24%
Coal-gas (with coke)	60%
Water-gas	60%
Water-gas, special quick-blast	75 to 80%
Producer-gas	80 to 85%

Assuming the calorific value of coal as 14 000 B.t.u. per lb. and the efficiency of the gas-making process 80%, the heat available at the engine is 11 250 B.t.u., which is equivalent to about one b.h.p. This duty, one b h.p. per lb. of coal, should therefore be expected from a well-equipped gas-power plant.

Station Economy.—Returning to the consideration of the plants under exhibit, the average station economy observed is shown in Table 2. Averages for several month's operation have in most cases been given so that the results represent the efficiency of the entire station, day in and day out, with various generating outfits running at varying load-factors, and including errors of measurements encountered in every-day operation. Although in some cases "over-dynamoed," the engines are generally underloaded and frequently so much so that good economy could hardly be expected. The average gas consumption per kw-hr. is 39.0 cu. ft. Assuming an average calorific value of 625 B.t.u. per ft. for coal-gas, water-gas or mixed-gas, the heat consumption is 24 400 B.t.u. per kw-hr., 18 200 B.t.u. per e.h.p-hr, and 14 500 B.t.u. per brake h.p-hr. The average cost of gas charged to the engine is 33.9c per 1000 cu. ft., which is in nearly all cases considerably above the cost in the holder to companies operating both plants, with the result that the gas works realizes a handsome profit from the electric station in addition to the decrease in cost per unit with increased production. This point will be brought out later. Assuming an average production-cost of 20c per 1000 cu. ft., the average cost of power is 0.83c per kw-hr., equivalent to 0.495c per b.h.p-hr. at 80% combined efficiency.

TABLE II. COST OF OPERATION.—FUEL ONLY.

Plant Number.	Character of Load.	Kind of Gas.	Per cent. of total Gas Generated, used for Engines.	Manufacturing Cost Gas. Cents per 1000 cu. ft.	Cost Charged to Engines. Cents per 1000 cu. ft.	Gas per kw-hr. at Switchboard.	Cost per kw.		Remarks.
							Gas Only.	% Steam Station.	
						ft.		%	
1	Railway	Mixed	54	18	37.57 at 18	43.75 28.40 46.57	1.65 1.07 0.84	.. 81 63.5	Av. 6 mo. All-day run. Gas at cost.
2	Arc.	Coal.		18	18	33.64	0.61	24.5	Av. 4½ mo.
3	Incan.	Coal.	31	..	62	53.2	3.3	..	Av. 6 mo. 1902.
4	"	Water.	30	..	59.3	41.6	2.46	..	Av. 20 mo. 1901–1902.
5	Arc. and incan.	Mixed.	37.5	..	34.6	..	..	..	Output not metered.
6	Incan.	Coal.	26	..	39.8	48.4	1.93	..	Av. 9 mo. 1902.
8	"	Coal.	5	19	33	28.5	0.94	..	Night run 65% rating.
9	"	Mixed.	19.5	..	29.5	41.7	1.22	..	Av. 6 mo. 1902.
10	"	Coal.	15.0	..	20	41.9	0.98	..	Av. 19 da. Aug. '02.
11	Incan. and Arc.	Natural.	100	10 10	15.0 16.0	12.4 21.5	0.18 0.34	.. 26	Special test. Av. 6 mo.
Average.		..	..	..	33.9	39.0	1.4	..	

Average cost per kw-hr. at 20c, Gas (excluding No. 11) 0.828
" cu. ft. Gas. per kw-hr 39.0

The comparative cost of steam and gas-power is well shown in Tables 3 and 4. In Table 3, two independent stations were operated during 1902, together with the gas works. The cost of coal in the steam plant was 1.38c per kw-hr. against 0.75c per kw-hr. in the gas plant, representing a saving of 45.5%, although the cost per 1000 B.t.u. of gas was 3.4 times that per 1000 B.t.u. of coal. Assuming calorific values of 14 000 and 625 B.t.u. per lb. and cu. ft. respectively, 92 000 B.t.u. were required per kw-hr. in the steam station, against 29 100 in the gas station, or a saving of heat in the latter of 68.5%.

TABLE III. PLANT NO. 1.

COMPARATIVE OPERATING ECONOMY.

Load.	Steam Station 1250 i.h.p. Averages for 6mo. Apr.-Sept.		Gas Station 685 b.h.p. Averages for 5 mo. May-Sept.	
	Railway, Incandescent Arc.		Railway.	
	1901.	1902.	1902.	
Kw-hr. per mo.	......	122 733	Kw-hr. per mo.	39 508
Lb. coal	761 058	802 507	Cu. ft. Gas	1 726 400
Per cent. ash	8 2	7.7		
Lb. coal per kw-hr.	......	6.55	Cu. ft. Gas per kw-hr.	43.75
Cost coal per ton, f.o.b.	......	4.02	Gas charged per 1000 cu. ft.	37.57c
Handling	......	.19	Price gas per kw-hr	1.65c
Total	......	4.21	Cost gas, actual	17.2c
Cost coal per kw-hr.	......	1,375c	Actual cost kw-hr.	75c.
			Per cent. saving cost per kw-hr. over coal.	45.5%
Watt-hours per lb, coal—a.m.	138.20	134.65	Watt-hours cu, ft. Gas—a.m.	24.33
Ditto—p.m.	164.40	166.02	Ditto—p.m.	21.40
Ditto—24 hr.	159.97	159.08	Ditto—24 hr.	22.23
B.t.u. per lb., estimated.	14 000	14 000	B.t.u. per cu. ft., est.	625
Watt-hours per 1000 B.t.u.—24 hrs	......	11.35	Watt-hours per 1000 B.t.u.—24 hrs.	35.6
B.t.u. per kw-hr.	......	92 000	B.t.u. per kw-hr.	29 100
B.t.u. per e.h.p-hr.	......	68 600	B.t.u. per e.h.p.	21 700
B.t.u. per b.h.p-hr, at 80%	......	55 000	Per b.h.p. at 85%	18 450
			Per cent. saving heat.	66.5%

SPECIAL TEST.—GAS STATION.

All-Day Run:		*Five-Hour Run.*	
Max. Watt-hrs. per cu. ft. Gas	35.3	Max. Watt-hr. per cu. ft.	40.9
Cu. ft. Gas per kw-hr.	28.40	Cu. ft. Gas per kw-hr.	25.0
" " " " e.h.p-hr.	21.20	" " " e.h.p-hr.	18.6
" " " " b.h.p-hr.	18.02	" " " " b.h.p-hr.	16.65
B.t.u. per b.h.p.	11 250	B.t.u. per b.h.p.	10 400

Note.—Both plants run 15 to 18 hours per day. Steam equipment consists of compound condensing engines and water-tube boilers. Average load factor of steam station higher than gas station.

In Table 4 the output was not measured, but the costs indicate the general balance of economy on the side of the gas station. The steam plant started operation on natural-gas at 10c per 1000, with a minimum of $3000 per year. It employed horizontal return tubular boilers fired by gas. One year after starting the gas plant, this minimum was reached and the company is now paying at the rate of over 16c per 1000 ft. The saving in total operating cost amounted to 40.5%. In the face of a 30% increase in station output, the gas consumption has been reduced by 93%. Previous to the replacement of the steam-equipment, an economy-test was run on the station, throughout 24 hours. The gas consumption at the boilers was 51.09 cu. ft. per i.h.p., developed at the engines, equivalent to about 86 cu. ft. per kw-hr. All engines were of the simple high-speed type, running non-condensing. A short preliminary test of the gas plant after installation showed an economy of 12.31 cu. ft per e.h.p-hr. During the six months ending August, 1902, the total gas consumption of the station, including heating, was 23.8 cu. ft. per kw-hr. Deducting approximately 7.5% for heating, the net consumption was 21.5 cu. ft., which is about 24% of that recorded on the steam station. It is equivalent to 12 cu. ft. per b.h.p. or a duty of 14 100 B.t.u. per b.h.p.

TABLE NO. IV. PLANT NO. 11.

COMPARATIVE COST OF OPERATION.—STEAM ENGINES VS. GAS ENGINES ON NATURAL GAS.

Year.	Gas ft.	Labor.	Repairs.	Oil and Waste.	Total.	Remarks.
		Steam Plant.		Gas-Fired Boilers.		575 i.h.p.
1897	9753.20	9725.26	600.00	1485.06	....	Gas rate, 10c per 1000 cu. ft. minimum reached in 1900. Avg. 1902, 15.9 per 1000 cu. ft.
1898	9320.70	8258.33	400.00	306.14	19 924.34	
		Gas Engine Plant.				800 b.h.p Increase Revenue.
1899	6318.92	6828.74	239.85	533.56	....	1897 % 1898 5.75
1900	3000.40	6782.01	499.09	592.92	....	1899 7.5 1900 13.5
1901	3000.00	7678.83	196.90	407.01	....	1901 11.0 1902 18.5
1902	3000.00	7626.87	261.04	379.70	11 836.41	Increase load 1898–1902, —30%
				Saving—	8087.93	= 40.5%.

Steam.................................$36.40 per yr. per h.p-capacity of station.
Gas.................................. 14.80 " " " "

Saving...........................$21.60 = 59.4%

ECONOMY TEST.

Steam Station:	*Gas Station:*
1898–24 Hours.	
Gas per i.h.p-hr.............51.09 ft.	Gas per kw-hr., Av. 6 mo...21.50 cu. ft.
" " kw-hr.............86 "	Calorific value gas, 1175 B.t.u. per cu. ft.

The gross station economy in the case of plant No. 6 is shown on Fig. 1. These observations were taken when the station was first started and operating under an extremely low load-factor.

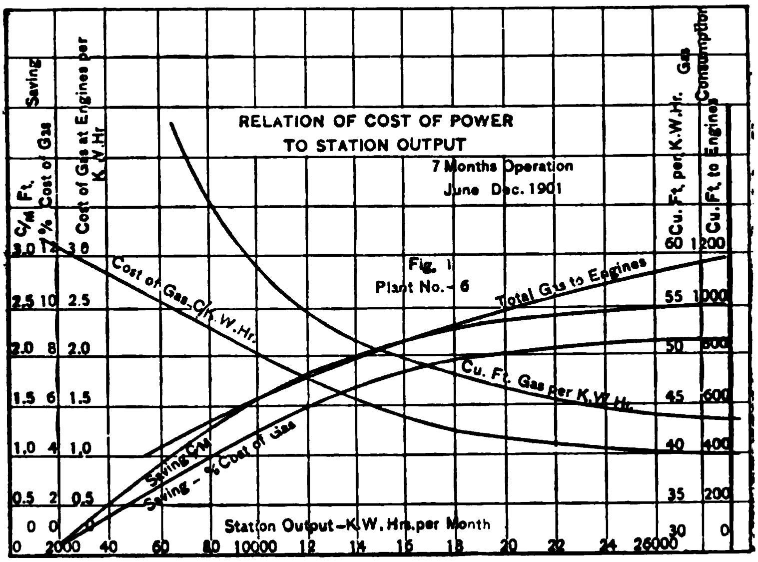

Fig. 1
Plant No.- 6

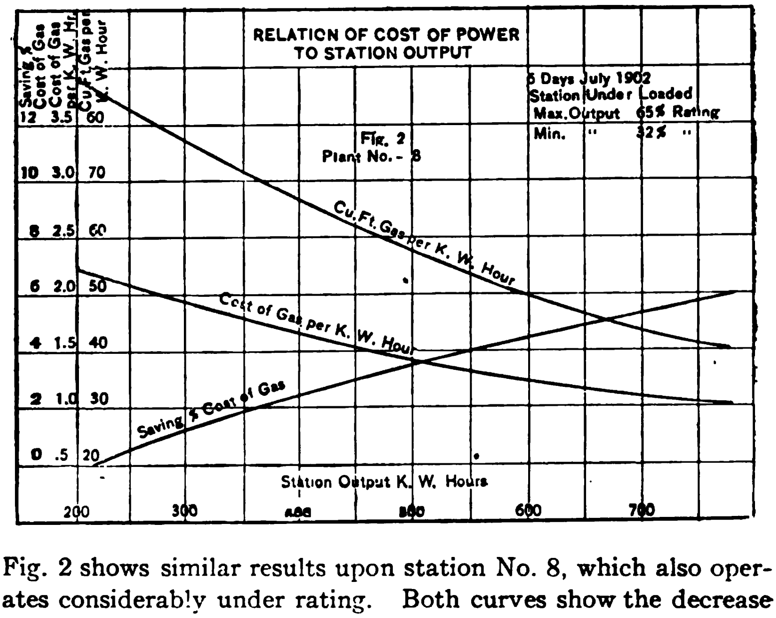

Fig. 2
Plant No.- 8

Fig. 2 shows similar results upon station No. 8, which also operates considerably under rating. Both curves show the decrease in cost of gas at the gas works, due to the increase in works output, necessitated by the electric station. The results may be considered as representative of conditions about as unfavorable to high economy in the prime mover as is usually encountered. Table No. 5 gives the operating cost of plant No. 9—135 h.p. capacity—for six months, during 1902. The average cost of gas is 1.22c per kw-hr. and the total operating cost 3.18c per kw-hr.

The above data shows in a general way the results that may be accomplished by gas-power plants, even though running under a burden of expense for fuel that would be quite out of the reach of steam plants. It goes without saying that much better results are obtainable in a plant of considerable size, of modern design and furnished with reasonably cheap fuel-gas.

TABLE V. PLANT NO. 9.
OPERATING COSTS GENERATING STATION.

Month, 1902.	Kw-hr. Generated.	Gas to Engines. 1000 cu ft.	Works Cost Materials per 1000 cu. ft.	Cu. ft. per kw-hr.	Cost Gas per kw-hr.	Total Cost Labor and Materials	Operating Cost per kw.	Remarks.
			c.		c.	$	c.	
Jan......	5465	187.6	32.2	34.4	1.1	149.07	2.74	Av. 19½%.
Feb......	4489	170.7	32.5	37.0	1.2	145.84	3.24	Total gas generated used by engines.
Mar......	4186	180.2	31.0	43.0	1.34	146.02	3.5	
Apr......	4670	226.6	31.0	48.5	1.5	168.31	3.61	
May.....	5124	227.1	28.0	43.4	1.21	161.70	3.16	
June.....	5246	231.3	22.5	44.0	0.99	153.73	2.93	
Average..	....	....	29.53	41.7	1.22	....	3.18	

Combined Gas and Electric Stations.—The theory of increase of profits from the operation of combined gas and electric plants is based upon the fundamental principle of reduction in cost per unit with increased output. If the net saving is sufficient to cover fixed charges upon the electric station, the way is clear to reap a double revenue, one from the electric station operating at a cost far below its steam-driven competitors, and the other from the gas station operating at a lower cost of production than before. The balance may of course be applied proportionately to the disbursement of fixed charges on both stations. It is usually the gas station that reaps the profit at the expense of the electric station. An adjustment of gas and electric rates can easily be made to prevent embarrassing competition.

Fig. 3 shows the cost of coal-gas, water-gas and mixed-gas for approximately 500 gas plants in the United States.[1] The curves were determined by the method of moments from a " shot-gun " diagram, and bring out the following points:

1. Cost per unit decreases as output increases, most rapidly in coal-gas plant and less rapidly in water-gas plants.

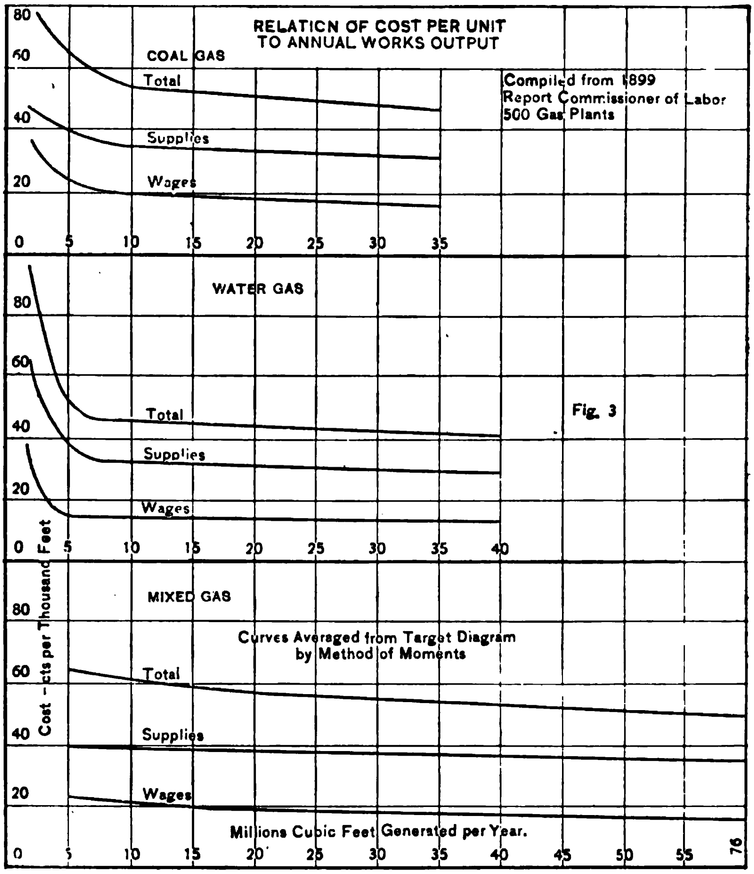

Fig. 3

2. Decrease in cost per unit in small plants of two to ten million cu. ft. per year output is very marked, being greatest in water-gas plants and least in mixed-gas plants.

3. The greatest opportunity for increasing revenue from combined gas and electric stations appears to be in the case of small

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[1] Report of the Commissioner of Labor on Gas and Electric Plants, 1899.

coal and water-gas plants under ten million cu. ft. output. The smaller the plant, the greater the profit.

In Table No. 2, Plants 1 to 10 inclusive operate combined gas and electric works and all successfully. Although production-cost[1] of gas is not in all cases available, in most cases the power-gas is charged to the engine at such a rate as to insure a handsome profit to the gas works. Table No. 6 shows results obtained from Plant No. 1. In this case the electric-plant was charged with gas at twice the cost of production. The gas works also realized a saving of 5.7c per 1000-cu. ft. nominal, or 10.3c actual, as a result of the increased output due to the gas-engines, which is 60% of the present production cost. The total saving thus amounted to 30.8c per 1000-cu. ft, nearly twice the production cost, and but little under the cost charged to engines.

TABLE VI. PLANT NO. 1.

PROFIT FROM COMBINED OPERATION OF GAS STATION WITH GAS WORKS.

Gas Works, Total Prdouction, Year 1901–2......38 241 000 cu. ft., – 10 100 ft./ton.

Costs.	Cost.	Cents per 1000 cu. ft.
Coal, at $4.03, 3780 tons	$15,208.70	40
Bench fuel	3,381.97	8.8
Labor	2.473.50	6.61
Repairs	676.11	1.63
Miscellaneous Expenses	184.90	0.48
Total Cost Gas	$21,945.18	57.56
Residuals.		
Coke at $6.00, 2375 tons	$14,250.00	37.20
Tar at 3.7c., 31 750 gal	1,172.00	3.18
Total Receipts—Residuals	15 422.00	40.38
Net cost gas	....	17.18c per 1000 cu. ft.

Cost gas charged against works, Av. 4 months	67.15c	per 1000 cu ft.
" " " " gas engines, av. 6 months	37.67c	" " "
Decrease cost gas due to increased production, actual	5.68c	" " "
" " " (basis of equal cost coal) See Table VII	10.31c	" " "
" " in per cent. of works cost	15.4%	
" " " engine "	27.4%	
Profit to gas works from engines	20.49c	per 1000 cu. ft.
" " " " " greater output	10.31c	" " "
Total profit, due to gas engines	30.80c	" " "
" " " " " " per cent. works cost	45.8%	

Table No. 7 shows the actual rate of decrease per month. In the last column results are reduced to a basis of equal cost of coal; viz., that of 1901.

Table No. 8 gives results in plants where similar data was available. The average saving recorded, due to gas-engines, was 5.2c per 1000 cu. ft, or 6.8% of initial works cost.[2] This, how-

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1. Revenue from sale of residuals deducted.
2. Residuals not deducted, maintenance included.

TABLE VII. PLANT NO. 1.

REDUCTION IN COST PER UNIT WITH PRODUCTION.

Mixed Gas.

	1000 cu. ft. Generated.			1000 cu. ft Increase.	% Increase.
	1901.	1902.			
April............	4115.5	5183.9	....	*1068.4	26
May............	3028.2	6612.4	....	3584.2	118
June............	3044.1	6845.3	....	3801.2	125
July............	4163.3	7176.6	....	3013.3	72.5
Aug............	4431.5	7775.0	....	3343.5	75.5
Average..........	3666.8	7102.5	....	3435.7	97.75

Total Works Cost cents per 1000 cu. ft. Gen.				Decrease Cost Nominal.		Decrease Cost at 1901 Coal. Actual.	
	1901.	1902.	Cost at 1901 Coal.	Cents per 1000 cu. ft.	%	Cents per 1000 cu. ft.	%
Apr............	62.63	66.59	61.60	-3.86	-6.15	1.03	1.67
May............	65.90	61.91	57.20	3.99	6.45	8.70	13.2
June............	68.90	62.67	57.90	6.23	9.05	11.00	16.0
July............	66.47	60.05	55.60	6.42	9.65	10.87	16.35
Aug............	67.40	61.32	56.75	6.08	9.02	10.65	15.8
1901 coal $3.75 1902 coal 4.02	67.15	61.49	56.86	Av. 5.68	8.54	10.31	15.34

*Gas Station operating light for testing out. April results not considered.

TABLE VIII.

COMPARATIVE COST OF GAS AS AFFECTED BY PRODUCTION.

Plant Number.	Output in cu. ft. per mo. before using Gas Engines.	Output in cu. ft. after Gas Engines were used.	Increase in Output.	% Increase.	Works Cost Gas.		Saving.		Remarks.
					Before	After	Cents per 1000 cu. ft.	% Cost of Gas before Engines were used.	
1	3666.8 3666.8	7102.5 7102.5	3435.7 3435.7	97.75 97.75	67.15 67.15	61.49 56.86	5.68 10.31	8.54 15.34	Per mo. Av. 4 mo. Estimated basis 1901 cost coal.
2	2250	3250	1000	44.5	..	18	8-10	..	Net charges, estimated.
3	590	924	334	56.5	65.6	63.99	3.06	5.5	Per mo. Av. 8 mo.
6	2192	4139	1947	89	42.5	39.8	2.7	6.4	Per mo. Av.8-12 mo.
10	....	....	....	50	..	..	5.0	...	20% Inc.cost of coal.
						Av....	5.2	6.8	

ever, is less than the actual saving by reason of the general increase in cost of coal at the time the last observations were taken, due to general stringency of fuel.

A comparison of the then prevailing market prices for fuel with the normal shows an increase of 24% in coal and 45% in coke.[1] Applying to Table No. 8, the percentage difference in saving due to difference in fuel-cost observed in Plant No. 1; viz., 15%—the average per cent. saving is 7.8% of works-cost—a material saving in any plant. This, of course, applies directly to the gas as distributed to customers.

These results, for consecutive months, are shown graphically in Figs. 4 and 5, which represent saving due to increased production, part of which is traceable to the electric-plant and part to consumers. In Plant No. 9 a saving of 24% was realized, and in Plant No. 6 the remarkable amount of 92% of initial works cost.

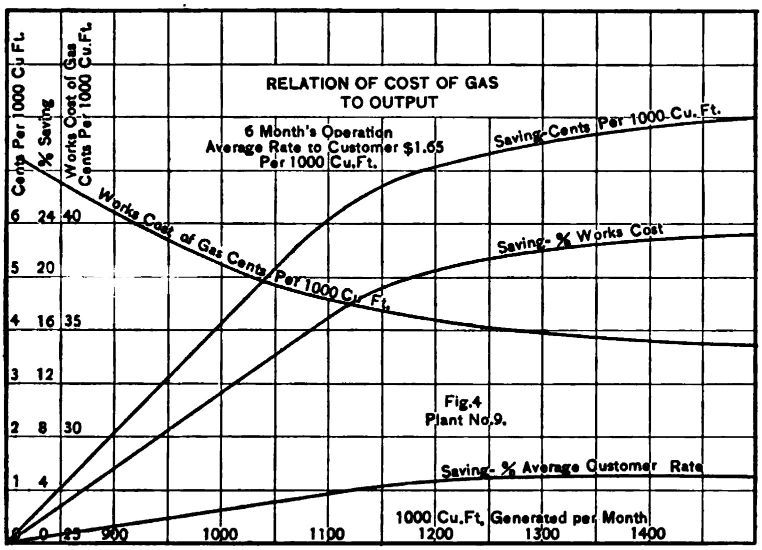

Fig.4
Plant No.9.

In order to bring out clearly the character of this saving due to increased production, the following case has been estimated along the lines indicated in the preceding pages. A ten-million-

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[1] The comparative market prices for fuel in the case of ten of the above plants averaged $3.63 and $5.10 f.o.b. works for coal and coke respectively, under normal conditions. The corresponding prices during 1902 averaged $4.50 for coal and $7.41 for coke, or an increase of $0.87 and $2.41 over normal for coal and coke respectively. See Table 9.

foot plant has been taken generating gas at 40c per 1000 cu. ft. works cost, including coal, bench fuel, labor, repairs, and miscellaneous material, residuals not deducted. Fixed charges have purposely been omitted. The gas is charged at works cost to the electric station It is assumed that the cost of gas for this plant, previous to absorption of the electric-plant, was 50c per 1000 cu. ft, and that the electric-plant generates electricity at twice the fuel cost, 3.2c per kw-hr. During normal operation with an output to the electric-plant of 30%, of the total amount of gas generated, the total net revenue was about $13'300; 45% of which was due to the electric station and 55% to the gas station. The operating costs will then amount to 46.4% of the net revenue.

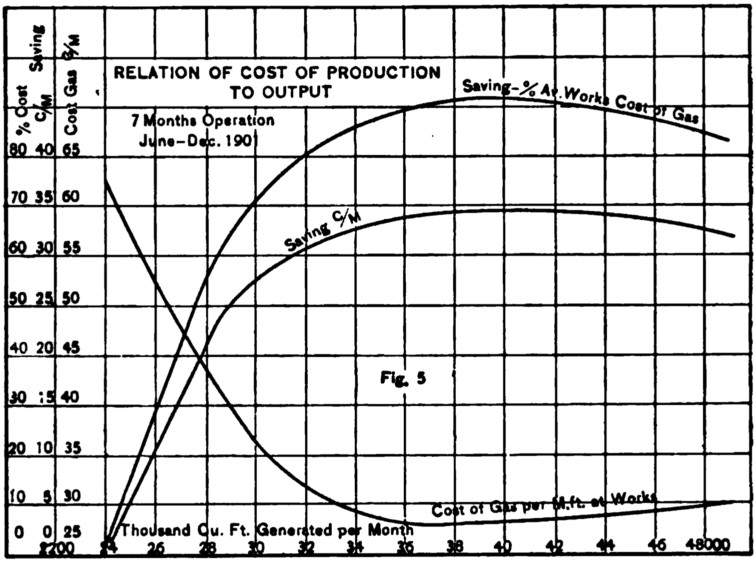

Fig. 5

Comparing the operations of the gas station *per se*, previous to and following the acquisition of the electric station, there is a net revenue of $5835 and $7344 respectively, or an increase of $1509; 25.8% of the original revenue. Figuring in the saving of 10c per 1000 cu. ft. due to increased production, the total increase amounts to 43% of the net revenue upon the original gas station.

Considering, finally, the combined works, the increase is $7449, or 127% of the original revenue, and adding again the saving 10c

TABLE IX.

FUEL COSTS AND PRICES PAID FOR RESIDUALS.

Plant No.	Gas Coal			Steam Coal.			Coke.			Tar	Remarks.
	Normal.	1901	1902	Normal.	1901	1902	Normal.	1901	1902	Normal	
1	3.75	4.02	4.02	....	3.83	..	6.00 (4.96 charged against works.)	..	7.00 7.50	c. 3.7	19c. per ton handling 1902 hard coal.
2	..	3.75	4.55	....	3.75	4.55	....	5.00	7.50	3.5	
3	3.00	4.00	5.00	3.00	..	5.00	5.00	..	6.00	3.5	Coke 8.00 outside.
4	..	..	....	2.50	..	..	5.70	..	8.60	..	Use coke only.
5	..	4.55	4.82	....	..	..	5.00	5.50	7.50		Av. frt. rate from mines $1.50 ton.
6	3.55	4.20	3.85 4.35	....	..	..	10c. bu.	..	..	..	Coal by contract.
7	..	..	3.75	....	..	..	4.00	..	7.50	3.5	
10	3.15	..	4.50	....	..	..	5.00	..	7.50	7.0	Coke 10c. bu. Ammonia 26c. per ton coal.
Av...	3.63	..	4.50	....	..	..	5.10	..	7.41	..	

Av. Increase: $0.87 = 24%. Av. Increase· 2.31 = 45%.

TABLE X. GAS WORKS YIELD.

Plant No.	Yield.			Kind of Gas Mfd.	Remarks.
	Gas. cu. ft. per ton.	Coke lbs. per ton.	Tar gal. per ton.		
1	9700 10 100	1260	7.5	Mixed.	
2	10 000 10 500	1350	8	Coal.	
3	10 500	1275	8	Coal.	
4	....	....	....	Water.	Coke used.
5	10 000	1350	....	Mixed.	Bench fuel 300 lb. per ton.
6	9000	....	....	Coal.	
7	9700	1300	8	Mixed.	Bench fuel 300 lb.
8	....	870	10	Coal.	
10	Ammonia 26c	per ton.			
Av......	9937 ft.	1233 lb.	83. gal.		

per 1000 cu. ft., the total increase is 145% of the net revenue of the original gas works.

Although these percentages will be considerably reduced by the consideration of investment charges, depreciation, sinking fund, etc., the fact remains that the saving due to combined operation is material and should appeal particularly to companies operating independent gas and electric generating stations.

*OPERATING COSTS AND PROFITS OF A TYPICAL GAS-ELECTRIC WORKS.

ASSUMPTIONS:

Output per year	10 000 000 cu. ft.
Gas per ton	10 000 "
Works-cost gas	40c per 1000 cu. ft.
Works-cost gas, before gas-engine used	50c " 1000 "
Cost at engine	40c " 1000 "
Coal	$3.75 per ton.
†Coke per ton, at $5.00 per ton	1230 lb.
Bench fuel per ton, at $4.00	300 "
Gas-tar per ton, at 4.5c	8.3 gal.
Line and meter loss, gas line	15%
Line and meter loss, electric system	10%
Average rate to gas customer, per 1000 cu. ft.	$1.25
Average rate to electric customer, per kw-hr	12c
Electric plant consumption of gas, % total output	30%
Gas per kw-hr. at switchboard	40 cu. ft.
Fuel cost per kw-hr. at switchboard	1.6c
Works cost per kw-hr. at switchboard	3.2c

REVENUE:

Gas:				
Gas to electric plant,	3000 cu. ft. at 40c		$1200	
Gas for distribution,	7000 cu. ft.			
Gas for sale, 85%,	5950 cu. ft. at $1.25		7445	
Total sale gas			$8645	
Residuals:				
Coke for sale, 465 tons		$2325		
Tar for sale, 8300 gal.		374		
			2699	
Total sales, gas works				$11 344

(*) Fixed charges omitted from this estimate.

(†) In coal-gas plants the sale of residuals constitutes an important part of the total revenue, so important in fact that during times of high-priced fuel it pays to manufacture coal-gas rather than water-gas, and sell residuals. The average yield per ton of coal is shown in Table No. 10, viz.: 10 000 cu. ft. of gas, 1230 lb. coke and 8.3 gal. tar.

Electricity:			
Kw-hr. generated $\frac{3000 \text{ cu. ft.}}{40 \text{ cu. ft.}}$	75 000		
Line loss 10%	7500		
Kw-hr. for sale	67 500		
Revenue from clectric station			8100
Total revenue from works			$19 444
COST:			
Gas:			
10 000 cu. ft. gas at 40c		$4000	
Net revenue station, exclusive of fixed charges	$7344		
Electric:			
67 500 kw-hr., at 3.2c	2160		
Net revenue station, exclusive of fixed charges	$5490		
Total cost to combined works			$6160
Total net revenue to combined works			$13 284

Per cent. due to electric station	44.7
Per cent. due to gas station	55.3
Electric station per cent. of gas station	81.
Operating cost per cent. of net revenue:	
Electric station	36.3
Gas station	54.5
Works	46.4

COMPARISON OF COSTS, BEFORE AND AFTER INSTALLING ELECTRIC STATION.

Gas Station.

BEFORE.		AFTER.	
Revenue:			
Gas for sale, 5950 cu. ft. at $1.25	7445	5950 cu. ft. at $1.25	$7445
		3000 cu. ft. at 40c	1200
Residuals	1890	Residuals	2699
Total revenue	$9335		$11 344
Costs:			
7000 cu. ft. at 50c	3500	10 000 cu. ft. at 40c	4000
Net revenue	$5835		$7344
		Increase	1509
		Saving 10 000 cu. ft. at 10c.	1000
		Total increase	$2509
Cost % net revenue	60%	Cost % net revenue	54.5%
		Cost % net revenue plus saving	32.4%

GAS AND ELECTRIC WORKS.

BEFORE.		AFTER.	
Revenue	$9335	Total revenue, gas, electric, and residuals	$19 444
Cost	3500	Cost—gas and electric	6160
Net revenue	$5835	Net revenue	$13 284
		Increase	$7449
		Saving—10 000 cu. ft. at 10c	1000
		Total increase	$8449
Cost % net revenue	60%	Cost % net revenue	45.4%
		Cost % net revenue plus saving	43.0%

DISCUSSION OF PAPER BY J. R. BIBBINS ENTITLED GAS-POWER FOR CENTRAL STATIONS.

RALPH D. MERSHON:—The speaker does not believe this paper gives a fair comparison of the relative value of gas-engines and steam-engines, in general, for electric work. A proper general comparison should include, not only the cost of fuel, but also the cost of depreciation, interest, repairs, and attendance charges. It is only when a full statement of the cost is given that true comparisons can be made. The speaker believes in the future of the gas-engine; in Germany, many plants, consisting of producers and gas-engines are now in use, and the number is increasing; the recent adoption of the " suction " generator has done much to hasten this development.

The author, on page 771, says that the cost of a 1000-h.p. plant for gas and steam is about the same. The speaker is of the opinion that the cost of a gas plant will be very materially greater, and hopes that the author can substantiate this statement by detailed figures. The speaker found in Europe that the calorific value of the various explosive mixtures used is generally much more nearly equal and is lower than shown in the table on page 775. He thinks also that the prices asked by American manufacturers for gas-engines are entirely out of reason, and that such excessive prices will retard the general use of gas-engines.

PHILIP TORCHIO:—The speaker is of the opinion that the very favorable results shown by Mr. Bibbins are due to the fact that he considers a small gas station; if he had based his comparisons on a larger station, the figures would not have been so favorable.

HERBERT A. WAGNER:—Unfortunately, all users of gas-engines cannot secure results as favorable as those cited by Mr. Bibbins. The speaker has recently removed a gas-engine plant and replaced it by steam-engines. The plant consisted of three 100-h.p. units, operating alternators and arc dynamos. The cost of operation, large at first, had increased to such an extent from year to year that the company was forced to make a change of some kind. It was decided to abandon gas-engines entirely. In the last year of the operation of this plant, the cost of energy was more than eight cents per kilowatt-hour; the largest single item was the cost of repairs and maintenance. In this plant, producer gas was generated solely for the gas-engines; the plant was run entirely apart from the gas-making plant.

H. G. STOTT:—On page 781, the author states that " the average cost of gas is 1.22 cents per kilowatt-hour, and the total operating cost 3.18 cents per kilowatt-hour." The cost of fuel is then 38% of the total cost, or the other costs of operation are 62%. In the ordinary steam plant, the cost of fuel is probably 70% of the total cost. This difference of 32% of the total cost of operation represents, of course, the increased cost of maintenance and labor for the gas-engine plant. These figures illustrate the differences in the two kinds of plants.

J. R. Bibbins (in reply to the Discussion):—The principal object of the paper is to place before you results and observations upon the operation of a number of gas plants of very moderate size and not to introduce comparisons with stations of larger output or with those operated upon producer gas, which of itself constitutes a separate and distinct field. The direct comparisons between steam- and gas-power plants have been confined to plants No. 1 and No. 11, upon both of which reliable data are available. The comparisons are, it seems to the speaker, perfectly legitimate, particularly in the case of Plant No. 1, where both steam and gas stations were operated simultaneously for the specific purpose of determining the relative economy; in both plants steam power has been replaced by gas power through "the survival of the fittest."

As to the comparative cost of steam and producer gas power equipment: leaving out of consideration the cost of holder capacity, the costs will be nearly equal. With this item included, the cost of the gas equipment is slightly in excess, depending upon the character of the producer employed—whether continuous or intermittent—and upon the requirements of the service—whether the power demand is reasonably constant or heavily fluctuating. The holder capacity to be provided is purely a matter of judgment and should be estimated in each individual case in a similar manner to steam-storage capacity in a steam plant. A prominent gas-engineer recently quoted the comparative cost of 1000-h.p. high-grade steam and gas plants as follows:

$100 per horse power for a steam equipment, consisting of compound condensing engines, electrical machinery, boilers, stokers, economizers, and coal-handling machinery; $125 per horse power for a gas equipment comprising high-grade engines electrical machinery, producers, coal-handling machinery and a 20 000-ft. holder, capable of supplying the plant at full load for about 20 minutes. If holder capacity is dispensed with in a producer plant and the engines simply draw their supply of gas directly from the producers under either slight pressure or suction, there is the risk of gas of non-uniform quality reaching the engine cylinder. Storage capacity obviates this to a large degree, and is evidently essential in the operation of electric plants where exact regulation is so much more important a requirement than, for instance, in driving blowing-engines by blast-furnace gas.

A possible explanation of the requirement of a higher grade of intelligence among European operators may be found in the character of engines used. Large engines are quite common abroad, due to long development and the great demand for cheap power. Many are of comparatively complicated construction and consequently require more-skilled attendants. It has been observed in the plants on exhibit that the grade of intelligence is a matter rather secondary to the personal prejudices of the operators. The greatest difficulty encountered in breaking in new men was to overcome their prejudices. But, with knowledge of the construction and operation of the plant and its superiority from the standpoint of comfort and safety to employes, this prejudice disappeared and more efficient operation of the plant resulted.

In plant No. 1 the entire station was operated without a single interruption for a period of six months through a regular shift by one attendant, formerly a wiper in the steam plant. This man had never held an engineer's position.

In reference to the calorific value of the various mixtures given on page 775, the values are for theoretically perfect mixtures. More air is however sometimes required than is called for by a perfect mixture, which may result in the lower values referred to by Mr. Mershon. But the speaker believes that the calorific value of mixture of the leaner gases is generally much lower than for illuminating and natural gas, which seems reasonable on account of the inert ingredients of producer and blast-furnace gases.

The quantity of jacket-water required depends largely upon the quality of the supply. If it contains no chemical or vegetable impurities, so that deposits in the jackets will not occur, the cylinders may be run hotter than with impure water and consequently less water will be required. On the average, about 4000 B.t.u. per brake h.p. are carried away in the jacket-water and the quantity, therefore, depends upon the terminal temperatures, which in winter might easily range from 40° fahr., inlet, to 200° fahr. outlet, if the water is good.

The field for commercial heating by jacket-water is of course not comparable with that by exhaust steam, from the fact that the latent heat is not available as in the case of steam.

These figures represent the temperature range of "in and out" jacket-water, which may be secured with good water during cold weather. The rate of flow can be determined from these temperatures and the total heat to be removed by the jackets.

[Replying to a question.] There are two general methods of governing; viz., the hit-and-miss, and the method of throttling the charge. It is safe to say that the former is thoroughly unsuited for driving generators. The latter is employed in several different forms, each with many prominent representatives. The method that is widely employed in both American and European engines is that of throttling a mixture of constant quality, under which conditions the maximum fuel-efficiency may be retained at all loads.

Replying to a question.] A considerable amount of experimental work has resulted in the employment of the spring coupling between engine and generator, and success seems to lie in this direction, together with the use of multi-cylinders. With flywheels of moderate capacity, a three-cylinder engine of the type shown gives a crank effort of such uniformity that the cyclical variation, expressed in angular degrees, falls within standard specifications for steam-driven generating units. It is found, however, that the best results in parallel operation are secured with the flexible coupling which deadens to a large degree the suddenness of the impulse following combustion. In the three plants cited—13, 14, and 15—parallel operation is an accomplished fact. All three plants operate cranes, hoists, and shop motors (all of the induction type) and the load fluctuates constantly, often through a range of 100% in a few seconds. In general, it is not necessary in a plant of several units to provide all engines with spring couplings. One unit may have a solid coupling and will operate satisfactorily with the remaining spring-coupled units. With double-acting engines the difficulties in parallel operation are of course halved and further reduced in the ratio of the number of cylinders employed.

The data from which Mr. Stott draws conclusions are given in No. 9, a plant of only 135 h.p. The cost of power in plants No. 1 and No. 11 should rather be taken as representative of the economy to be obtained from a gas plant of moderate size. Mr. Stott also draws attention to the importance of labor and maintenance. In plant No. 11 these items aggregate 52% of the total operating cost of the steam station and 67.5% of the gas station. The increase in percentage is not due to acutal increase in operating cost, but rather to the decrease in the fuel item which renders the maintenance item the more conspicuous. The average maintenance cost for the steam station was $10 400 as against $8000 for the gas station of nearly double the capacity.

(Communicated after Adjournment by J. R. Bibbins.)

Replying further to the discussion upon the comparative importance of fixed charges upon steam- and gas- plants: the following figures are obtained from Plant No. 11. The costs are expressed in terms of brake horse power per year of capacity of station, for the reason that accurate records of kilowatt-hour output are not at present available.

INVESTMENT.

Items.	Steam Plant.	Gas Plant.
Building and Real Estate	$17 000.00	$17 000.00
Steam Machinery, complete	51 000.00	
Gas " "		60 000.00
Total	$68 000.00	$77 000.00
Equipment cost per h.p.	139.00	96.25
Building " " "	35.00	21.25
Machinery " " "	104.00	75.00

FIXED COSTS.

Interest on investment, 5%	$3 400.00	$3 850.00
Depreciation, Building, 3%	390.00	390.00
" Machinery, 10%	5 100.00	6 000.00
Taxes, Insurance, Legal, etc., 3%	2 040.00	2 310.00
Total fixed charges	$10 930.00	$12 550.00
Per brake h.p. per year	22.30	15.70
Net operating cost	36.40	14.80
Total operating cost	$58.70	$30.50
Saving	28.50	= 48%

Concerning the quantity of jacket-water required under ordinary conditions of operation, two cases are given below representative of summer and winter extremes. Assuming a duty of 11 000 per brake h.p-hour at the engine and 40% of the heat to be imparted to the jackets, the jacket-water will carry away 4400 B.t.u. per hour.

	Winter.		Summer.	
	Temp. of Water.	Sensible Heat per lb.	Temp. of Water.	Sensible Heat per lb.
Leaving jackets	200° fahr.	168 B.t.u.	200° fahr.	168 B.t.u.
Entering "	40° fahr.	8 B.t.u.	65° fahr.	33 B.t.u.
Range "	160° fahr.	160 B.t.u.	135°	135 B.t.u.

4400/160 = 27.5 lb. per h.p-hr. 4400/135 = 32.6 lb. per h.p.-hr.
Water per h.p.- hr. = 0.44 cu. ft. 0.52 cu. ft.

A simple and efficient method of reclaiming the heat discharged in the exhaust is successfully used in one plant operating both steam and gas equipments. The exhaust gases are passed through a tubular heater resembling an ordinary feed-water heater. By shutting off the water ordinarily used to cool the exhaust and running the jackets at about 150° fahr., the jacket-water in circulating through the heater is raised to a temperature of 200° to 210° fahr., by the heat from the exhaust gases. This water may then be used for boiler feed or for heating buildings. By this method the actual heat efficiency of the gas-engine is increased from 25% to 68%.

DISCUSSION OF J. R. BIBBINS' PAPER AT PHILADELPHIA.

January 11, 1904.

J. B. **KLUMPP**:—The speaker is of the opinion that the author has not done justice to the gas-engine in that he has considered it principally in connection with a gas works, and not as a separate proposition, operating with producer gas, which is the way that best results can be obtained from gas-engines. The gas-engine will probably, in the course of time, displace the steam-engine in many applications, although the increasing use of the steam-turbine, the internal-combustion engine of the Diesel type, and the possible introduction of a gas-turbine, must be held in view when this matter is considered. The character of the load for a gas works and an electric lighting plant is very different, in that the electric lighting plant has a short peak-load, while with the gas plant, only the total daily output need be considered. This daily output usually reaches a maximum in early winter, though sometimes the maximum is as great in September or October. The ratio of maximum to yearly output is frequently as high as 1/240 to 1/260.

If a gas-engine plant is to be used as an auxiliary to a gas works, the load of the gas-engines must be regarded in precisely the same light as an additional number of consumers, and a corresponding increase in the gas-making plant must be supplied. The maxima of the two loads will probably occur at the same time, and the engine cannot be regarded as using part of the output of apparatus that would otherwise be idle. The gas company must, for safe operation, hold a reserve capacity which should be available at the time of maximum daily output. In a few cases where a gas works has too great reserve capacity, it would be more economical to dispose of the surplus gas by the introduction of gas stoves for summer use, which would not be a tax upon the maximum daily output. If the proper increase is made in gas-making apparatus, there are few cases in which the total cost, including interest, depreciation, and repairs would be decreased.

Gas-engines using illuminating gas will probably never be introduced extensively, on account of the great cost of making this gas. Producer gas is undoubtedly the best for use with gas engines, except, of course, natural gas. With producer gas, the fuel cost can be reduced to from 0.35 to 0.5 cents per kilowatt-hour, which compares favorably with steam.

It is doubtful if gas-engines operating producers will give high efficiency at light loads, as the producers will either have to operate at a small fraction of their capacity, or the storage capacity provided be shut down for a time; hence the fuel consumption will not be reduced in proportion to the output. Moreover, the engines themselves at fractional loads, have a low efficiency. The cost of operation will be reduced both on account of lesser fuel cost and lesser attendance cost; but repairs on the engines will undoubtedly be greater than on a steam-engine.

The proposition to use the hot jacket-water for the heating system, would hardly be applicable beyond the engine-room itself.

[Communicated after Adjournment.]

by J. R. Bibbins.

The author cannot agree with the speaker from Philadelphia that the gas-engine employed in conjunction with gas works for generating electric power represents an undesirable auxiliary and one that is incapable of securing to the gas works an all-day output of greater uniformity and consequently of less cost per unit. To be sure, with the usual electric light loads daily and yearly maxima for both gas and electric plants would nearly coincide, but it should be remembered that the electric plant affords an opportunity to work up an all-day factory motor-load which is ordinarily outside of the reach of the gas works. In any event, gas-storage capacity may be so readily provided, as compared with steam or electric storage, that the coincidence of gas and electric load maxima becomes a secondary consideration. On the other hand, a heating load is undesirable as it represents an idle investment through a large part of the year, and is incapable of control or limitation by contract to definite hours as in the case of electric-power load.

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