Carl Hering.

TRANSACTIONS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS.

VOL. XVII.

PUBLISHED BY
THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS,
26 CORTLANDT STREET,
NEW YORK CITY, U. S. A.
1901.

McIlroy & Emmet, Steam Printers, 106 & 108 Liberty St., New York.

OFFICERS AND MEMBERS OF THE COUNCIL.

1899-1900.

PRESIDENT:

CARL HERING,
Term expires 1901.

PAST-PRESIDENTS:

DR. NORVIN GREEN, 1884-5-6.
FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
PROF. ELIHU THOMSON, 1889-90.
PROF. W. A. ANTHONY, 1890-91.
ALEX. GRAHAM BELL, 1891-2.
FRANK J. SPRAGUE, 1892-93.
DR. EDWIN J. HOUSTON, 1893-4-5.
DR. LOUIS DUNCAN, 1895-6-7.
DR. FRANCIS B. CROCKER, 1897-8.
DR. A. E. KENNELLY, 1898-1900.

VICE-PRESIDENTS:

Terms expire 1901.
ARTHUR V. ABBOTT,
GANO S. DUNN,
W. L. R. EMMET,

Terms expire 1902.
DR. MICHAEL I. PUPIN,
DR. SAMUEL SHELDON.
GEORGE F. SEVER.

MANAGERS:

Terms expire 1901.
HERBERT LLOYD,
DR. SAMUEL SHELDON,
GEORGE F. SEVER,
CHARLES P. STEINMETZ.

Terms expire 1902.
CHARLES S. BRADLEY.
DR. MICHAEL I. PUPIN,
WILLIAM D. WEAVER,
C. O. MAILLOUX.

Terms expire 1903.
W. S. BARSTOW,
JOHN J. CARTY,
CALVIN W. RICE,
RALPH D. MERSHON.

Terms expire 1901.

TREASURER:

GEORGE A. HAMILTON,
463 West Street, New York.

SECRETARY:

RALPH W. POPE,
26 Cortlandt St., New York.

Board of Examiners:

WILLIAM MAVER, JR., Chairman.
ROBERT N. BAYLIS,
F. A. PICKERNELL,
JESSE M. SMITH.
TOWNSEND WOLCOTT.

STANDING COMMITTEES APPOINTED BY DIRECTION OF COUNCIL.

Executive Committee:

CARL HERING, Chairman.
GANO S. DUNN,
J. W. LIEB, Jr.,
R. W. POPE,
GEO. A. HAMILTON,
C. O. MAILLOUX,
Dr. SAMUEL SHELDON,

Committee on Papers and Meetings.

W. S. BARSTOW, Chairman.
EDWARD CALDWELL,
R. T. E. LOZIER,
CALVIN W. RICE,
W. J. HAMMER.
T. C. MARTIN,
GEORGE F. SEVER,

SUB-COMMITTEE ON RECEPTION.

T. C. MARTIN, Chairman.
W. J. HAMMER,
R. T. E. LOZIER
C. O. MAILLOUX,
Dr. SAMUEL SHELDON.

Library Committee.

W. D. WEAVER, Chairman.
EDWARD CALDWELL,
W. J. JENKS,
GANO S. DUNN,
J. W. LIEB, Jr.,
GEO. A. HAMILTON,
R. W. POPE.

Committee on Units and Standards.

Dr. A. E. KENNELLY, Chairman.
Dr. FRANCIS B. CROCKER.
DR WM. E. GEYER,
GEO. A. HAMILTON,
WILLIAM D. WEAVER.

Committee on Standardization.

Dr. FRANCIS B. CROCKER, Chairman.
Dr. ARTHUR E. KENNELLY,
JOHN W. LIEB, Jr.
CHARLES P. STEINMETZ,
L. B. STILLWELL,
Prof. ELIHU THOMSON.

Committee on Co-operative Research:

DR. A. E. KENNELLY, Chairman.
Prof. W. A. ANTHONY,
Dr. SAMUEL SHELDON,
Dr. FRANCIS B. CROCKER,
CHAS. P. STEINMETZ,
Prof. ELIHU THOMSON.

Local Honorary Secretaries:

RICHARD H. PIERCE,
1409 Manhattan Building, Chicago.

H. F. PARSHALL,
8 Princes St., Bank E. C. London, Eng.

JAMES S. FITZMAURICE,
210 George St., Sydney, N. S. W.

Prof. ROBERT B. OWENS,
McGill University, Montreal, P. Q.

GEORGE P. LOW, 320 California St., San Francisco, Cal.

CONTENTS.

REGULAR MEETING, NEW YORK, JANUARY 24, 1900.

REGULAR MEETING, NEW YORK, February 28, 1900.

REGULAR MEETING, NEW YORK, March 28, 1900.

REGULAR MEETING, NEW YORK, APRIL 25, 1900.

ANNUAL BUSINESS MEETING, NEW YORK. MAY 15, 1900.

SEVENTEENTH GENERAL MEETING, PHILADELPHIA, MAY 16–18, 1900.

SEVENTEENTH GENERAL MEETING CONTINUED, PARIS, AUGUST 16, 1900.

REGULAR MEETING, NEW YORK, SEPTEMBER 26, 1900.

REGULAR MEETING, NEW YORK, OCTOBER 24, 1900.

REGULAR MEETING, NEW YORK, NOVEMBER 23, 1900.

The INSTITUTE is not, as a body, responsible for the statements of fact or opinions advanced in papers or discussions at its meetings, and it is understood that papers and discussions should not include matters relating to politics or purely to trade.

Constitution, Article VII, Sec. 2.

TRANSACTIONS
OF THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Vol. XVII. JANUARY TO DECEMBER. 1900.

New York, January 24th, 1900.

The 139th meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order by President Kennelly at 8.25 P. M.

THE SECRETARY:—At the meeting of the Council this afternoon, the following associate members were elected:

Name.	Address.	Endorsed by
BEHREND, BERNHARD A.,	Erie, Pa.	C. P. Steinmetz. T. C. Martin. W. D. Weaver.
BEVERIDGE, EDMUND WALTER,	Assistant Engineer, The G. I. P. Railway Co., India, Sirud Khandish District, Bombay, India.	Ralph W. Pope. N. S. Keith. F. E. Kinsman.
DENHAM, JOHN	Electrician, Cape Government, Cape Town, South Africa.	W. M. Mordey. J. E. Lloyd. A. E. Worswick.
EVANS, PAUL H.	Chief Engineer, Mexican General Electric Co., Apartado 408 Mexico City.	C. F. Beames. A. E Worswick. JohnW.Thompson
GREENWOOD, GEORGE,	Electrical Engineer and Superintendent, Jalapa Railway and Power Co., Jalapa, V. C. Mexico.	JohnW.Thompson C. F. Beames. A. E. Worswick.
HOLMES, GWYLLYM R.	Holmes-Rose Electric Co., 2842 Parkwood Ave., Baltimore. Md.	H. K. McCay. Gano S. Dunn. M. C. Schwab.
HYDE, J. E. HINDON,	120 Broadway; residence, 48 West 11th St., New York City.	C. F. Chandler. C. A. Doremus. Henry Morton.
MAGNUS, BENJAMIN	Electrical Engineering Student, Columbia University; residence, 22 E. 111th Street, New York City.	Geo F. Sever. Fitzh. Townsend. F. B. Crocker.
NILES, HARRY B.	Electrical Engineer, Ferrocarrillos del Distrito, American Club, Mexico City.	JohnW.Thompson C. F. Beames. A. E. Worswick.

Pfeiffer, Alois J. J.	Engineer, Thomson - Houston Co., 5 Piazza Castello Milano, Italy.	H. A. Foster. W. J. Davis, Jr. A. H. Armstrong.
Poole, Charles Oscar	General Superintendent Electrical Dept. San Francisco Gas and Electric Co,, 229 Stevenson St.; residence, 452 Bryant St., San Francisco, Cal.	J. A. Lighthipe. Geo. P. Low. F. A. C. Perrine.
Powelson, Wilfred Van Nest,	Government Inspector, Electrical Appliances. General Electric Co., Schenectady, N.Y.; Lieutenant U. S. Navy.	Eskil Berg. Ernst Berg. Chas. P. Steinmetz
Saylor, Frederick Alexander,	Chief Electrician, U. S. S. Chicago; residence, Reading, Pa.	W. E. Chappell. Arthur L. Rice. T. P. Thompson.
Selden, R. L. Jr.,	Deep River, Conn.	F. G. Strong. R. W. Pope. T. C. Martin.
Shearer, J. Harry	Electrical Engineer, National Electric Light Co., Apartado, 639 Mexico City, Mexico.	John W. Thompson C. F. Beames. A. E. Worswick.
Shephard, Robert R.	Erecting Engineer, Mexican General Electric Co., Apartado 403, Mexico City, Mexico.	C. F. Beames. A. E. Worswick. John W. Thompson
Thompson, Milton T.	Constructing Engineer, Mexican General Electric Co., Apartado 403, Mexico City, Mexico.	C. F. Beames. A. E. Worswick. John W. Thompson
Zabel, Max W.	Draughtsman and Student of Patent Law with John A. Brown & Cragg, 1450 Manadnock Bg.; residence, 454 North Ave., Chicago, Ill.	D. C. Jackson C. F. Burgess M. C. Beebe.
Total 18.		

The following associate members were transferred to membership:

Approved by Board of Examiners, September 7th, 1899.

Walter Douglas Young, Electrical Engineer, B. & O. R. R., Baltimore, Md.

Approved by Board of Examiners, October 20th, 1899.

Lozier, Robert T. E. Electrical Engineer, Member of Firm of Bullock Electric Co., St. Paul Bldg., New York City.

Approved by Board of Examiners, Dec. 8th, 1899.

H. A. Storrs, Assistant Engineer, U. S. Engineer's office, New London, Conn.

The President:—Since our last meeting the Institute has suffered by the death of two of our well-known members, Mr. James Hamblet has served the Institute for some years, both as vice-president and manager. His contribution to the electrical interests, work and fraternity extend over half a century.

Mr. Dana Greene had rendered valuable and active service to the INSTITUTE, not only as Manager on the Council, but also in contributing papers. By his extensive general knowledge and genial influence he greatly promoted electrical engineering progress in those branches which he made peculiarly his own. His untimely death will be greatly deplored not only by all our members who knew of his work, but by the favored few who were acquainted with his charming personality. The Council has at its meeting to-day passed resolutions to be communicated to the families of these gentlemen, and has ordered suitable obituary notices to be printed in the TRANSACTIONS.

The following paper was then read by Mr. Fitzhugh Townsend on "A New Method of Tracing Alternating Curves."

*A paper presented at the 139th Meeting of
the American Institute of Electrical Engineers, New York, January 24th, 1900,
President Kennelly in the Chair.*

A NEW METHOD OF TRACING ALTERNATING CURRENT CURVES.

BY FITZHUGH TOWNSEND.

The following method of determining the instantaneous values of alternating current waves recommends itself by its simplicity, accuracy, and rapidity. In addition to this, the method is capable of determining directly a curve of induction.

Fig. 1 shows the connections for taking the curves of electromotive force and magnetic induction simultaneously. E is the E. M. F., the curve of which is to be determined, R_1, R_2 and R_3 are ohmic resistances, e is a small transformer with open magnetic circuit, and C is the contact maker. This consists of a disk, the perimeter of which, in a bipolar alternator, is divided into two sections. One section only is conducting, and since the disk is mounted on the shaft of the machine, or on that of a synchronous motor, the current can flow in the circuit of the contact maker only during one-half of a period. d is a Weston portable voltmeter, connections being made directly to the movable coil.

DETERMINATION OF A CURVE OF INDUCTION.

The double throw switch b shown in Fig. 1 should be closed so as to connect points 3 and 4 to 5 and 6, switch a being open. The required curve can then be obtained by noting the deflections of the instrument, d, corresponding to successive angular positions of the contact brush f. The theory on which this is based is as follows: Owing to the construction of the contact maker, the current i, which passes through the instrument d, flows during one-half of a period only. During the active half period, however, i is proportional to E, the electromotive force : i will therefore be an interrupted current having the form of the electromotive force as shown in Fig. 2. The position of the

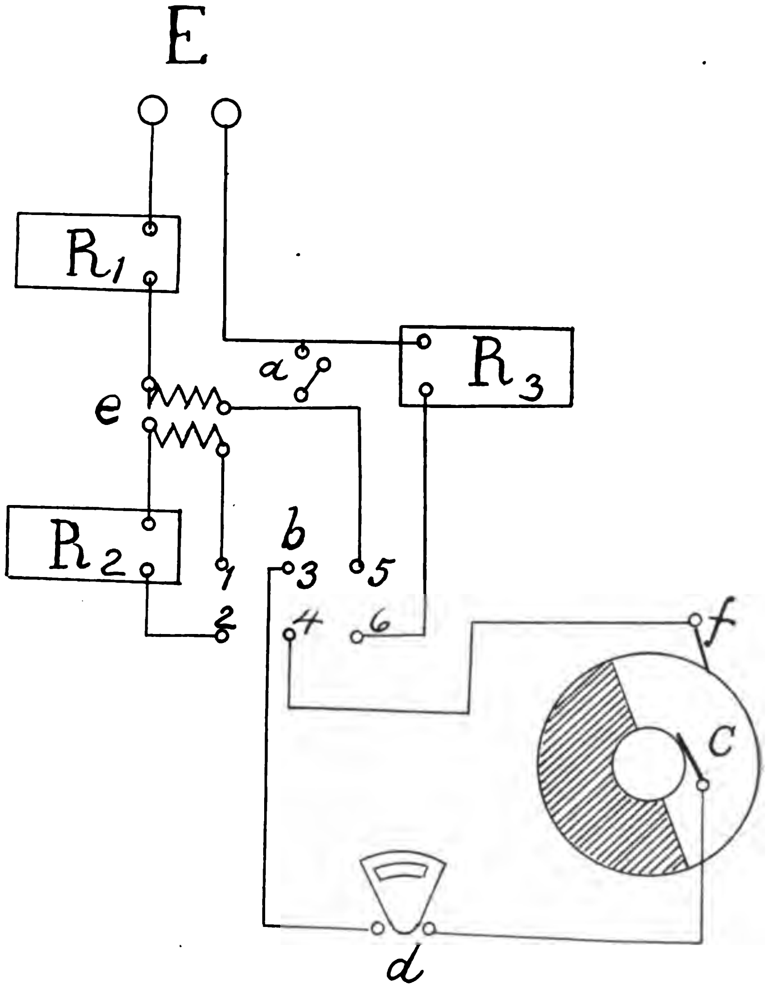


Fig. 1.

time interval $t_2 - t_1$ will depend on the angular position of the contact brush f.

The deflection of the voltmeter will be proportional to the number of impulses per second. Each impulse being proportional to the time integral of the current during the interval $t_2 - t_1$.

Therefore,

$$\theta = K\int_{t_1}^{t_2} i\,dt = K_1\int_{t_1}^{t_2} E\,dt = K_2\int_{t_1}^{t_2}\frac{d\,B}{d\,t}\,d\,t = K_2(B)\Big|_{t_1}^{t_2} = K_3\,B$$

If the brush *f*, and consequently the interval $t_2 - t_1$, are moved through a period, and the values of θ at different points noted, the curve of the induction B will be obtained.

Determination of a Curve of Electromotive Force.

The switch *b* should now be closed so as to connect points 3 and 4 to 1 and 2. The contact maker and the voltmeter will then be in the secondary circuit of the small transformer *e*. Close switch *a*. The curve of the electromotive force may then be obtained, as in the case of the curve of induction, by noting the deflections of the voltmeter for different angular positions of the brush *f*. It can be shown readily that this is the case. If the constants of the transformer *e* are suitably related to each other, the primary current will be the same in form as the electromotive force E, and practically independent of the value of the secondary current i. This will be brought about when the electromotive force of mutual induction in the primary, due to the secondary current is only a small percentage of the E. M. F., E. We will then have

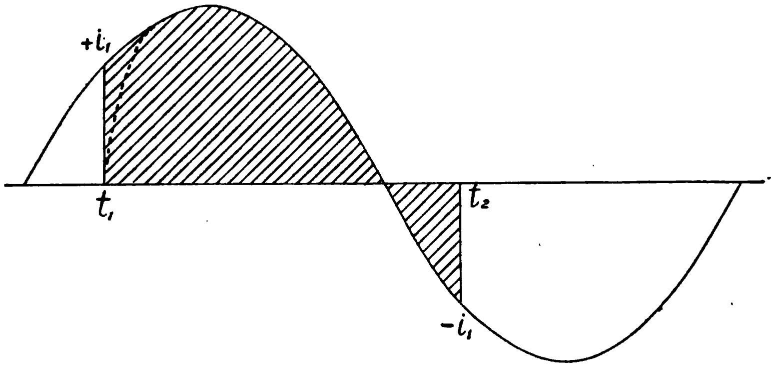


Fig. 2.

$$i = K \frac{d\,E}{d\,t} \text{ and } \theta = K_1 \int_{t_1}^{t_2} \frac{d\,E}{d\,t}\,d\,t = K_2\,(E)_{t_1}^{t_2} = K_3\,E$$

Fig. 3 shows curves of B and E in a transformer obtained as described above. The form of these curves requires a few words of comment.

Any complex harmonic electromotive force generated by a properly designed alternator, may be represented by the equation $E = A_1 \sin p\,t + A_3 \sin 3\,p\,t + A_5 \sin 5\,p\,t +$ etc. $+ B_1 \cos p\,t + B_3 \cos 3\,p\,t + B_5 \cos 5\,p\,t +$ etc. Therefore,

$$B = \int E\,dt = -\left(\frac{A_1}{p} \cos p\,t + \frac{A_3}{3p} \cos 3\,p t + \frac{A_5}{5p} \cos 5\,p\,t + \text{etc.}\right)$$

$$+ \frac{B_1}{p} \sin p\,t + \frac{B_3}{3p} \sin 3\,p\,t + \frac{B_5}{5p} \sin 5\,p\,t + \text{etc.}$$

It appears from this that the curve of induction should differ less from the sinusoidal form than the curve of electromotive force, since the relative amplitudes of the upper harmonics are made less by the process of integration in proportion as their frequency exceeds that of the fundamental. Thus the third harmonic in the curve of induction has one-third the relative amplitude which it has in the curve of E. M. F. Similarly, the fifth harmonic has its relative amplitude divided by five, and so on.

Also the complexities in the induction should be the reverse of those in the electromotive force. In other words, a peak in curve B should correspond to a depression in curve E.

In order to prove the accuracy of the method, and to show that the curve B in Fig. 3 is correct, the true curve of induction was constructed from the electromotive force curve by a process of integration. The constructed curve was found to coincide with the experimental curve as shown.

The method of obtaining the curve of induction from the curve of E. M. F. by integration, is extremely laborious. The method described in this paper is the only one to-day which is capable of determining the curve of induction directly, thereby saving much time and trouble.

In determining the curve of induction, the phase depends on the relative values of the resistance and inductance of the circuit through the interrupter. A variation of the amplitude of

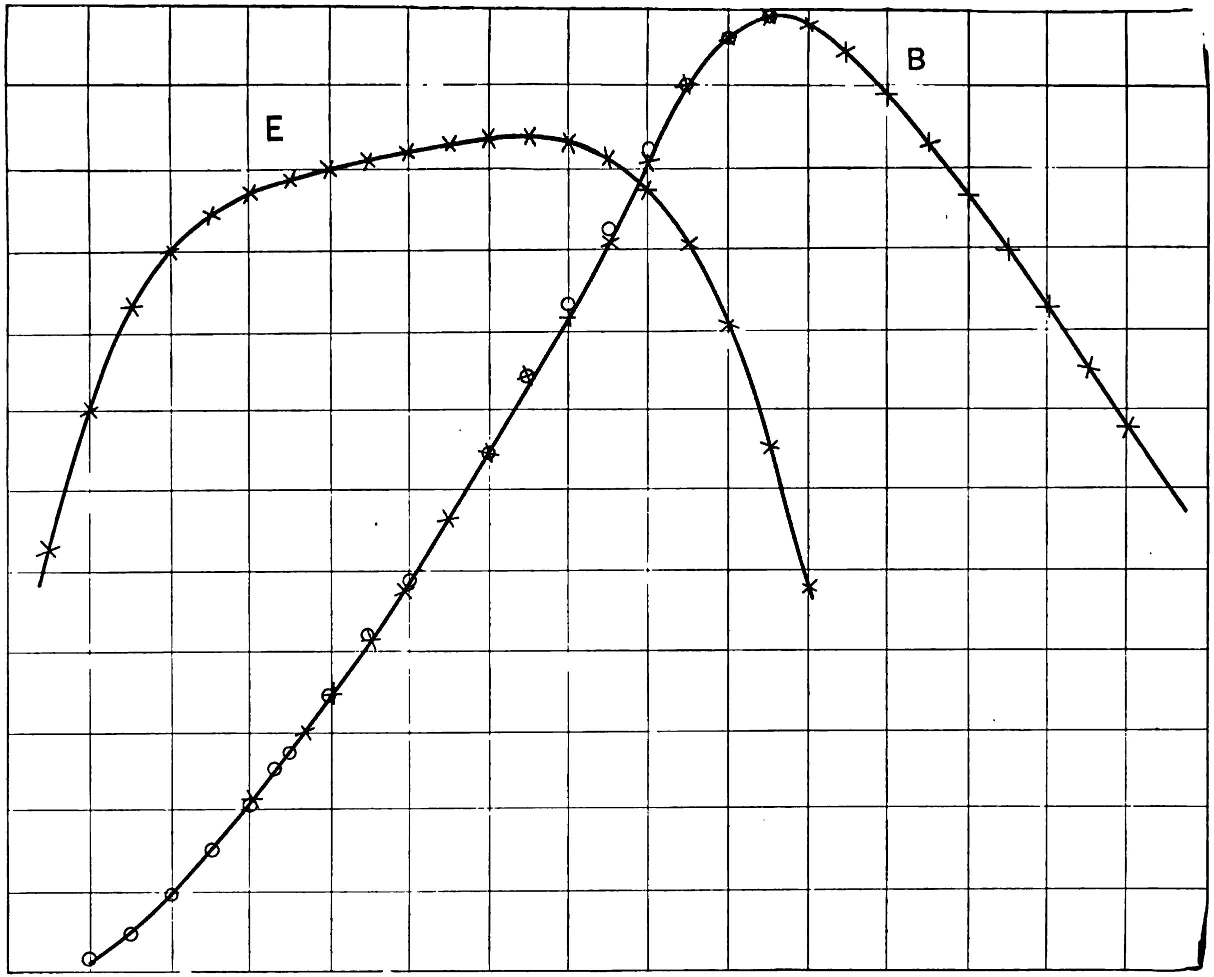


Fig. 3. Points Determined Experimentally, ×. Points Determined by Calculation, O.

E will not change the phase of the curve to a perceptible extent.

In the case of the determination of E, the phase depends on the values of resistance and inductance in both the primary and secondary circuits of the transformer e. As in the case of the B curve, varying E with the same resistance and inductance in both primary and secondary circuits, will not change the phase appreciably.

The shape of the wave E will remain unchanged, so long as three conditions which are essential to the accuracy of the method are maintained.

The first of these is that the electromotive force of mutual induction in the primary circuit due to the secondary current shall be small compared with the total E. M. F. impressed on the primary circuit.

If this were not the case, the secondary E. M. F., and therefore the secondary current would not be proportional to the rate of change of the primary current.

In the transformer used in taking the curves shown, the coefficient of mutual induction M was found to be .00076. The secondary current never could be more than 0.03 amperes without producing too large a deflection of the voltmeter needle, therefore the electromotive force of mutual induction due to the secondary current could not be more than

$$E_m = p\ M\ C_2 = 760 \times .00076 \times 0.03 = .017,$$

which shows that the first condition of accuracy mentioned above would be fulfilled to within 1% for an impressed electromotive force as low as 1.7 volts.

The second condition is that the resistance R_1 and R_2 in Fig. 1 shall be great compared with the inductances of the primary and secondary circuits of the transformer e.

In the case of the curve shown in Fig. 4, the values of R_1 and R_2 were 30 and 50 ohms respectively. If E is a complex harmonic, R_2 must be greater than R_1.

Since

$$i = K\frac{d\,E}{d\,t},$$

the upper harmonics in the secondary current i will be much more pronounced than they are in the curve E.

If R_2 were not large compared with the secondary inductance, the form of the current i might be quite different from that which it should have in order to give accurate results.

The third condition which must be fulfilled in order that the curve obtained may be correct in shape, is that the time constant of the secondary circuit shall not exceed a certain value.

When a circuit containing inductance is closed, the current does not reach its value E/R until a certain time has elapsed, and during this interval the current is

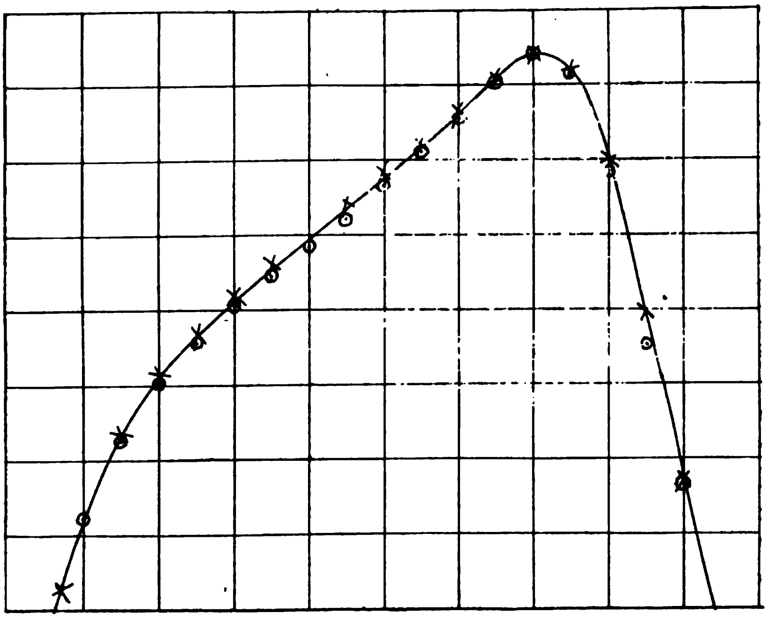


FIG. 4. Points Obtained by Zero Method, ⊙. Points Obtained by Present Method, ×.

$$i = \frac{E}{R}\left(1 - e^{-\frac{R}{L}t}\right)$$

Evidently if the time constant is too large, or if R/L is too small, the integral of the secondary current will not be the entire shaded area of Fig. 2, but will be bounded at the make by some curved line instead of a perpendicular, as shown by the dotted line in the figure. This would be a source of error, which would come in more and more as the secondary current integral drew near to its zero value. When this integral is a maximum, the make takes place at $i = 0$, hence at this point of the curve the effect would not occur. The result of the time constant of the circuit would therefore be a decrease in the relative size of the ordinates near the zero points, and also a slight shifting of the zero points with respect to the maximum, the maximum ordinate remaining unchanged both in intensity and phase. It is probable, then, that the effect of too great a time constant in the secondary circuit would result in making the curve come out more pointed than it really is, and slightly bent over sideways.

The curve of a complex harmonic electromotive force shown in Fig. 4 was determined as a test of accuracy: It furnishes a comparison between the method described here, and the well-known zero method in which a telephone receiver is used as the indicating instrument. As may be seen, there is a satisfactory agreement in the readings obtained by the two methods.

The curve of Fig. 4 was determined at a frequency of 120 periods per second. By increasing R_1 and R_2, it would evidently be possible to obtain curves at much higher frequencies. Mechanically, the method lends itself readily to this, inasmuch as the action does not depend on an instantaneous contact. This is a very advantageous feature, especially at high frequencies.

The transformer *e* used in these experiments was wound on a wire core 1½″ in diameter. There were 100 turns both in the primary and secondary windings.

The following are the principal constants of this transformer:

L_1 (on open secondary)	.00307	henrys.
R_1 " " "	.179	ohms.
L_2 " " primary	.00152	henrys.
R_2 " " "	.096	ohms.
M	.00076	henrys.
Resistance of voltmeter	.87	ohms.
Inductance " "	.00034	henrys.

Of course, only relative values are given by the readings of the voltmeter. In order to obtain absolute values, some means of calibration must be adopted. The easiest way to accomplish this is to switch the apparatus in series with some electromotive force, either direct or alternating, the maximum value of which is known. The deflection obtained divided by the true value of the electromotive force it represents will be the constant of the instrument for the particular amounts of resistance and self-induction which may be connected in the primary and secondary circuits of the transformer *e*.

The fact that the brush *f* makes contact for a half period and not for a very small fraction of a period, is a great advantage, inasmuch as the difficulties of a method of instantaneous contact are usually due to the short time of contact, making it hard to keep the apparatus in good working order. With the interrupter described here, however, there is no more difficulty than with an ordinary direct current commutator, and in fact rather less, as sparking, which is always the main evil of the commutator is practically absent in the interrupter.

In addition to the above, the present method seems to be the only one by which the curves of magnetic induction or quantity of electricity can be determined simultaneously with those of electromotive force and current.

Alternating Current Laboratory,
Electrical Engineering Dept.,
Columbia University,
New York City, January, 1900.

Discussion.

Dr. Samuel Sheldon:—I have been very much interested in reading this paper and hearing the description of this ingenious piece of apparatus. But it seems to me that in order that the instrument may give directly the curve of induction, that the two halves of the cycle of alternation must be perfectly symmetrical; that is, the positive flux of current must have the same time relation that the negative flux has. I cannot see from an examination of the mathematical equation that there is any difficulty with the equation. But a general equation should, if correct, be applicable to every case. It does not seem to apply to the case of the exaggerated curve shown in Fig 5, or at least, the contact-maker would not yield the correct curve of induction. Let the rectangular curve represent the time relation of the E. M. F. With proper arrangement of apparatus this will also be the curve of current. The relation which must exist between the induction and the time, in order to produce the curve of E.M.F., is represented by the dotted curve. The dotted curve is the integral curve of the E. M. F. curve. Now the curve which would be yielded by the contact-maker as described in the paper, the contact being maintained for half a cycle, would not coincide with this dotted curve of induction. The voltmeter readings will be proportional to the algebraic sum of the areas lying between the E. M. F. curve, the time axis, and the time intercepts of making and breaking contacts. A slight inspection will show that the curve passing through the points enclosed in circles would be the one which would be yielded by the contact-maker.

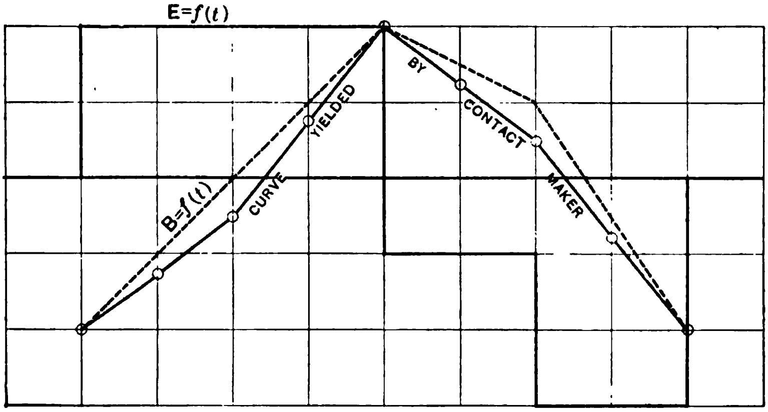


Fig. 5.

The difficulty in using a telephone and contact-maker with, say, the Mershon method is two-fold. In the first place the ordinary frequencies of alternating currents give a musical tone by means of the contact-maker, to which the ear is not particularly sensitive, and it is difficult to distinguish the intensity of a minimum, providing one cannot get absolute silence. In the second place, with a contact-maker having any breadth of contact at all, it is impossible to balance a variable E. M. F. against a constant E. M. F. Therefore, unless the contact's breadth be infinitesimal silence cannot be obtained. If, however, one uses a contact of sufficient breadth to be sure that the contact is made with every revolution of the contact-maker (of breadth, not necessarily to half a cycle), and makes use of the voltmeter as described in the paper *i. e.*, really as a ballistic galvanometer, then one can get a curve such as is yielded by an ordinary contact-maker and a very satisfactory one, without the liability of the contacts getting out of order.

In this use of the Weston voltmeter we have still another important adaptation of that valuable instrument. I have had occasion to use a Weston voltmeter for ballistic work, and it perhaps may be of interest to some who may not know it, that the Weston voltmeter will give deflections or throws in response to instantaneous quantities of electricity passing through it which are directly proportional to these quantities. Now a ballistic galvanometer has been defined by a good many different people as a galvanometer which has a needle which has a large moment of inertia and which has a long period of swing.

DR. PUPIN:—And small damping.

DR. SHELDON:—That is sometimes put in, yes.

DR. PUPIN:—Always.

DR. SHELDON:—Well, all right. It does not make any difference. It is not necessary that the ballistic galvanometer should have these qualities. If we calibrate a Weston voltmeter in a proper manner it can serve the purposes of a ballistic galvanometer just as well as the old fashioned kind. Those who have ever had occasion to take hysteresis curves by the step-by-step method, using a galvanometer which has a long swing of from 12 to 15 seconds, with two or three minutes' wait before the needle comes to rest after each swing, know what a tedious process it is to get a hysteresis curve. Yet the hysteresis curve can be taken with a Weston voltmeter of the ordinary round pattern switch-board style, having its series resistance removed, and it can be taken in less than two minutes, with a sufficient number of points to give accurate results, if the curve is properly integrated.

MR. FITZHUGH TOWNSEND:—With regard to that objection about determining the curve of induction, I have never attempted to determine the curve of induction from an unsymmetrical electromotive force. In all practical machines, good machines, and almost all alternating current machines, the positive half of the wave is the same as the negative half of the wave, and in that case I think the method holds good. A slight modification of the method which I have not yet tried, which would involve the use of two brushes, would I think obtain a symmetrical curve of induction, but that is more or less a *tour de force.* I have, therefore, only devoted my attention to the treatment of curves which were symmetrical with respect to the zero line.

MR. CHARLES P. STEINMETZ:—During late years no end of different methods have been brought out to take instantaneous readings of electrical quantities, mostly differing from each other by a different kind of contact-maker or a different material used, or other such minor qualities, or an improved method of using it. Now the method brought before us to-day essentially differs from previous methods, as far as I know them, by, I believe very favorable features. In its general principle this method described here consists of the following: To get instantaneous readings of a quantity, we derive from this quantity another quantity, which is a differential of the former, and take integral readings, that is average values of the latter quantity. We thereby get rid of most of the difficulties incident to instantaneous readings. We are independent of the width of the contact. We are independent of the impossibility of getting an absolute point-contact of no duration, and of the difficulties due to the arc following the contact-brush for some appreciable time. There are some limitations to this method, which after they are pointed out will probably be overcome. The source of error shown in Fig. 2 as due to the current not assuming instantly the full value, I do not consider so essential, because there is another error compensating for it. In Fig 2, the current in the moment when the circuit is broken, does not instantly drop to zero, but gradually dies out by a small arc continuing to carry the current. This gradual dying-out of the current compensates for the error mentioned in the paper to a certain extent. If you think of it still more, the error introduced by the current not stopping instantly, depends on the voltage at which you operate, and gets larger with increase of voltage, while the error due to the current not instantly reaching full value gets less with increase of voltage, thus theoretically you can always find a voltage, where the errors just neutralize each other. Practically, therefore, the method should give very accurate results provided that the errors are small enough *per se*, so as not to require perfect compensation.

The principle of this method as brought out here, however, can be applied in many different ways. It is shown only for determining the induction curve of the machine. This I do not consider as so very important, because you can get this curve of induction, although a little more laboriously, from the electromotive force curve; but you can apply the same method wherever you want instantaneous values of a quantity, and are able to get differential values of this quantity. To illustrate, for instance, one of the problems of great importance at present is to determine the variation of the rate of rotation of flywheels of slow-speed engines which are intended for use with synchronous apparatus as alternators, synchronous motors, etc. What you want to get there is the instantaneous displacement of the flywheel from the position it would have at uniform rate of rotation. Now the differential of this displacement is the velocity of the flywheel. Assume that on the shaft of the flywheel you have a small dynamo with constantly excited field, the field, for instance, excited by a storage battery. Take average or integral values of the electromotive force given by this dynamo, then you see these integral values give you direct the position of the flywheel. You would in such a case probably counterbalance the largest part of the electromotive force of the small dynamo by a storage battery with a constant electromotive force, to get a larger variation relatively than the very small variation of speed, and you would have to develop this method like you would have to develop any method.

But I believe that integrating or averaging the differential values of the quantity of which you want instantaneous values can be applied to many cases, and in some cases which are probably more important than the determination of instantaneous values of electromotive force, since there are no suitable methods in existence for such other cases.

DR. M. I. PUPIN :—I do not think that Dr. Sheldon's objection is a very serious one, for the reason that Mr. Townsend already pointed out. The method which Mr. Townsend describes is intended to analyze curves that are obtained in ordinary machines, well designed, not badly designed machines. If a machine is badly designed it is unworthy of investigation; the less you fuss with it the better. But even with a badly designed machine such as that would be which Dr. Sheldon presented on the blackboard, by a slight modification of the method as Mr. Townsend has already indicated, using two brushes, the difficulty could be gotten around. In all our commercial machines the electromotive forces and the currents are perfectly symmetrical on the two sides of the axis of the abscissæ. In that case the method will work all right. Now so far as any errors are concerned, I think that Mr. Townsend has rather enlarged them or made them appear more serious than they really are,—the source of error, namely the time constant. The time constant comes in the curve not rising instantaneously to its full value when you close the circuit and not falling off to zero when you break the circuit. That does not amount to much, because for other reasons you have to make the resistance large in comparison to the inductance of the circuit. In that case of course you have the time constant, a very large quantity; the current will in a very small fraction of the half period come to its full value. So that error really does not amount to anything appreciable. It certainly is very much smaller than other errors of observation that we meet with in investigations of this kind. The errors of observation in investigations of this kind are nearly one per cent. If any body does as well as that he is fortunate, and this error introduced by having the time constant a little bit too small will not be anything more than a very small fraction of one per cent.

Mr Steinmetz has said that we do not care so very much for the curve of quantity. Well, I think we do. You see in our present measurements we have three different kinds of instruments, fundamentally different. We have the voltmeter and the ammeter and the ballistic galvanometer—not in the way that Dr. Sheldon defined it, but in the way that it ought to be defined. The one measures the rate of variation of the quantity of electricity; that is the ammeter. The other measures in dynamo-electric machines the rate of variation of a magnetic quantity, this is the voltmeter; and the third one, the ballistic 'galvanometer, measures the quantity, either the quantity of electricity or the quantity of magnetism. Now in this method that Mr. Townsend brought before us to-night, we have another method which resembles the ballistic, to be sure, but still it is a different story from the ballistic, altogether a different story —measuring quantities, measuring the quantity of electricity and the quantity of magnetism directly, not in a roundabout way by integrating a curve. Whoever has made the calculations of integrating a periodic curve knows that there are a great many sources of error, very much greater sources of error than you meet with in experimental work of this kind. Some of us might say ; what is the use of measuring the quantity of magnetism or the quantity of electricity? There are investigations and that too not only of purely scientific interest but also of very great commercial and engineering value in which we do care for quantity of magnetism, quantity of induction and quantity of electricity.

I mention this for the purpose of bringing out something which Mr. Townsend has not brought out. This method was evolved in our laboratory in connection with an investigation which should be mentioned here. He has worked now for over a year very faithfully over a difficult problem—the problem of determining, what I choose to call, the dynamical hysteresis loop.

If you will allow me, I will point out the importance of this loop. If you determine an alternating electromotive force curve, and the corresponding current curve by a sliding contact, or any other way, and from the secondary E. M. F. curve, determine the curve of induction in a transformer, and then you plot a curve of Fig. 6, taking from the abscissæ the ampere turns in the primary, for the ordinates you take the total induction B of the transformer. You get the curve of Fig. 6 which I call the dynamical hysteresis loop. Its area represents the hysteresis and Foucault current loss per cycle. That is the total loss in the transformer, provided, of course, the secondary is not closed. But if the secondary is closed, then that is the total work done in the transformer, taking in hysteresis, Foucault current primary $I^2 R$ and secondary load.

Well, you see, the determination of curve in Fig. 6 is a very important thing. It enlarges our idea of the hysteresis loop. If you have no secondary current then you can study exactly what is going on in the iron while it is being magnetized and demagnetized. If you have a very high degree of lamination there are no appreciable Foucault current losses at ordinary commercial frequencies and in accordance with investigations which have been done abroad (and we have done some work of this kind in Columbia University owing principally to the perseverance and exertions of Mr. Townsend) then the hysteresis loop of Fig. 6 becomes more nearly like the statical hysteresis loop, determined with direct current and very slow cycles. If you magnetize the iron very slowly, the curve develops sharp corners as you all know. But you probably never get corners with alternating currents. Now, of course, if the impressed primary electromotive force is a simple harmonic, the induction will be a simple harmonic, and we can derive the induction curve very easily from the curve of the secondary electromotive force. There is no difficulty at all in doing that. But if the primary impressed electromotive force is a complex harmonic, the induction will be

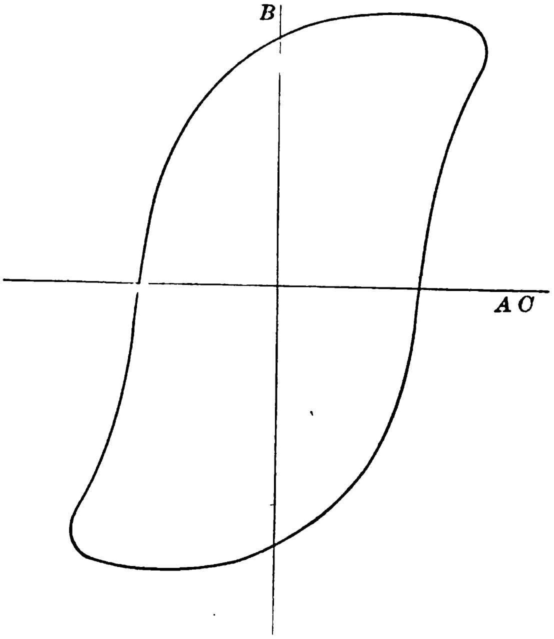


FIG. 6.

a complex harmonic, and if you try to deduce the induction from the secondary electromotive force you have to go through a lot of most tedious calculations. Mr. Townsend's method avoids this completely. It saves, therefore, a tremendous amount of labor and liability of error.

There is another thing that we have been trying to do for years and could not get it. How could this extended idea of the hysteresis loop be applied just as well to the losses in condensers? The reason that we get a hysteresis loop which is not an ellipse is because the permeability of the iron is a variable quantity. Now if you take a condenser you will find that the condenser capacity varies with the voltage just as the permeability varies with the magneto-motive force applied to the transformer. The static permeability, that is the specific inductive capacity, varies with the applied electromotive force; and just as in the case of the transformer, you get a hysteresis loop, so in the case of a condenser you also get a hysteresis loop. Now one way in which this variability or permeability manifests itself in the transformer is this: If you have a simple harmonic electromotive force the current is distorted; it has complex harmonics; now if you take a condenser, and impress a simple harmonic electromotive force upon it the current will be complex harmonic. But mind you, the difference of potential in the condenser will be a simple harmonic just the same as the secondary electromotive force in the transformer is a simple harmonic of the impressed E. M. F. You can plot the curve of hysteresis and other losses, whatever they may be in exactly the same way as you do in the case of iron. You take, not the magnetomotive force but the electromotive force for abscissæ (that is the difference of potential of condenser). For ordinates you plot, not the quantity of magnetic induction, but the quantity of electric induction Q, that is the quantity of electricity, and then you get the points of the hysteresis loop which looks something like curve of Fig. 6. You get the hysteresis loop for condensers just the same as for iron and you can estimate your losses and study how the whole thing acts. You do not only get the losses but you actually get the curve and see how those losses are brought about. Now this is a very interesting thing from a purely scientific standpoint and very important from the engineering standpoint and ought to be studied. Now in the ordinary sliding contact method of plotting curves we cannot determine the quantity of electricity directly; but if we use Mr. Townsend's method we can get that just as accurately as we can determine the voltage by a voltmeter. That seems to me to be a very important point.

Mr. Townsend:—With regard to the error of the time constant, it depends, of course, on the ratio of self-induction and resistance in the circuit containing the contact-maker and the instrument. If the resistance is sufficiently high for the current to have the true form of the rate of change of the E. M. F., it is found in practice that no error due to the time constant of the circuit can be detected.

In order to prove this, I determined a curve with no external resistance in the circuit. In other words, R_2 in Fig. 1 was made equal to zero, the instrument in series with the contact-maker being connected directly across the secondary of the transformer *e*. Under these circumstances, at a frequency of 120, the error due to the time constant amounted to about two per cent. In this case, however, the method was not correctly used. To comply with the theory, R_2 must be sufficiently great to make the current through the instrument proportional to the time rate of change of the electromotive force to be measured. When this condition is fulfilled, it will be found that the error due to the time constant cannot be detected.

MR. STEINMETZ:—This method of getting the dielectric hysteresis loop of the condenser was first applied, as far as I remember, some years ago by Dr. Bedell at Cornell University. Unfortunately Dr. Bedell has not been so successful as Dr. Pupin in getting a condenser with considerable internal losses but had condensers of very high efficiency. The hysteresis loop he got was so extremely flat and narrow as to be within the errors of observation, amounting to something less than three or four per cent. of the total volt-ampere capacity. But there are condensers which have an excessive internal loss so as to show a large loop and make this phenomenon more pronounced. However, no change of capacity with the voltage was observed by Dr. Bedell nor by me in condensers.

I do not want to be misunderstood by Dr. Pupin. I did not say that I do not care for the magnetic induction, but I did not consider it so very important to get a new method for it, because it can be derived from the current and electromotive force by integration. As a rule, in the usual method of getting instantaneous values of electromotive force you get them say from five to five degrees apart, and then you merely add the total value of 180 degrees and from this value you always add one value at one side,—say for 185°, 190°, etc., and subtract one value at the other side, say 5°, 10° etc., and you have the curve of induction. Now, that can de done for the whole curve in a very few minutes. However, obviously it is an advantage to derive it directly, only it is not so absolutely important.

I fully realize the importance of getting the curve of magnetic induction, the more as for many years I have been satisfied that the general custom of claiming some great and unknown advantages for a sine wave of electromotive force, is not warranted, but that in many cases the sine wave of electromotive force is about the worst you can get. Certain forms of distorted waves give a considerably lower magnetic flux in alternators, transformers and other apparatus, at the same induced E. M. F., and consequently a higher efficiency. Now you see that it is quite interesting to get the easy way of illustrating why it is, that for instance with the distorted wave of the ironclad unitooth alternator at the same impressed E. M. F. and same frequency, the hysteresis loss in transformers is from eight to twelve per cent. lower than with the sine wave, while certain forms of distributed armature windings give hysteresis losses in excess to those given by a sine wave.

DR. PUPIN:—I am aware, of course, of Dr. Bedell's article, but at that time when the article was published we had already done our work at Columbia University on that very thing, so we still claim the priority although we did not publish anything on the subject.

Another thing, Dr. Bedell's curve of hysteresis was, as Mr. Steinmetz remarked, quite within the errors of observation, so we feel rather uncertain as to whether what he got was really a hysteresis curve or simply a record of his errors. These errors can be obviated by employing very large condenser capacity. We have condensers at Columbia University which mount up to over 240 microfarads, so that we can draw on that as much as we please, and in that way of course we can increase the hysteresis loop to anything we desire. Another point was touched by Mr. Steinmetz, namely, the disputed question whether a peaked electromotive force curve, since it produced a flat induction curve, is not preferable in certain cases, can be decided by experiment in following the use of this contact-maker. It is a disputed question. Mr. Steinmetz maintains (and he does it of course partly for selfish reasons, because he must support his rule of hysteresis loss), that if a curve is a flat curve, although, of course, the area enclosed would be a larger one, the total loss would be smaller, because the loss depends only on the maximum of induction. Now, if that is really so it is a very interesting fact. I am inclined to believe it to be so. But still we would like to have some direct experimental evidence, and if this new method of plotting the curves of induction directly can help us to that, why that of itself is worth all the labors that Mr. Townsend spent on the designing and construction of this sliding contact.

MR. STEINMETZ:—I may say in this respect that not everything is published immediately after it is found out, but sometimes very many years after, even more than seven years. The first proof that the distorted wave gave the lesser hysteresis in the transformer was found by the wattmeter about ten years ago, before the laws of hysteresis were discovered. At the time it was not understood. Afterwards I hunted up the old tests and found the first experiment regarding the effect of the wave distortion or rather the effect of different types of alternators made by wattmeter reading, dating back before the time of my studies of the hysteresis law.

DR. PUPIN:—Yes, but I am afraid if we go into this discussion there will not be any time left for this paper, because I do not believe implicitly in the wattmeter readings. I would not accept them without an investigation as to the construction of the wattmeter and the way that it was used; so that I would not pay much attention to that. We all know that wattmeter readings are not reliable when we have harmonics in the circuit; that special precautions must be taken to ensure the accuracy of the readings. Now whether in these wattmeter readings to which Mr. Steinmetz referred, those precautions were taken or not I do not know. I do not think they were.

MR. STEINMETZ:—I do not quite agree that wattmeter readings are not reliable. It is true that theoretically an error is introduced by the inductivity of the potential circuit, and in scientific investigations of extreme accuracy this error would undoubtedly be serious. In practice, however, where as a rule no attempt is made to get a higher accuracy than one-fourth per cent., this wattmeter error is generally negligible.

Sometime ago I made an investigation in this respect and found that with certain commercial voltmeters the inductance error is still below one per cent. at 1500 cycles. The wattmeter error is of the same magnitude for non-inductive load, and increases with the increasing phase displacement of the main current, but becomes noticeable only at very low power factors, below 20%. The exciting current or open circuit current of a transformer, however, has quite a high power factor, from 50 to 65%, and in this case the wattmeter error due to the fundamental wave, is still negligible, that due to the higher harmonic small, and since the power of the higher harmonics is a small part of the total power, the maximum possible error due to the wattmeter is of far lower magnitude than the difference of hysteresis loss observed with different wave shapes.

There being no further discussion, the following paper entitled "Notes on Single-Phase Induction Motors and the Self-Starting Condensing Motor," was read by Mr. Steinmetz.

A paper presented at the 139th Meeting of the American Institute of Electrical Engineers, New York, January 24, 1900. President Kennelly in the Chair.

NOTES ON SINGLE-PHASE INDUCTION MOTORS,

AND

THE SELF-STARTING CONDENSER MOTOR.

BY CHARLES PROTEUS STEINMETZ.

I.—GENERAL.

1. In two previous papers, July, 1897, and February, 1898, of the TRANSACTIONS, I have given the theory and calculation of the polyphase induction motor and the single-phase induction motor, and shown that at or near synchronism the magnetic field in either can be considered as consisting of two equal magnetic fluxes, superposed upon each other in quadrature in time and in space.

In the polyphase motor both of these fluxes are proportional to the impressed E. M. F. less the impedance voltage of the primary current (the latter considered in its proper phase relation) thus equal to each other at all speeds. In the single-phase motor only one of the magnetic fluxes, that in the line of magnetization of the primary exciting coil, or the main magnetic flux, is proportional to the impressed E. M. F. less impedance drop, while the second magnetic flux, in quadrature with the axis of the primary exciting coil, or quadrature magnetic flux, falls off from equality with the main magnetic flux at synchronism to zero at standstill, or if by a starting device a quadrature E M. F. is impressed upon the motor in starting, to the quadrature magnetic flux given by the starting device, or auxiliary magnetic flux. In consequence thereof, while in the polyphase motor the torque equals secondary energy current times induced E. M. F., $e^2 a_1$, in the single-phase induction motor it is secondary energy current times quadrature induced E. M. F., $e^2 a_1 (1-s)$, when assuming the quadrature E. M. F., and thus the quadrature flux to fall off proportional to the slip s.

2. Thus the calculation of the single-phase motor load curves is the same as that of the polyphase induction motor, except that:

1st. In the single-phase induction motor in the equation of torque, the factor $(1-s)$ has to be added.

2nd. In the single-phase motor the admittance and the impedances are different from those of the same motor on polyphase circuit.

Since the magnetic field of the single-phase and the polyphase motor is the same at synchronism, the total volt-amperes excitation are the same, that is in the three-phase motor on single-phase circuit the total exciting admittance is three times, in a two-phase motor on single-phase circuit it is two times that of the same motor on polyphase circuit.

The primary self-inductive impedance on single-phase circuit is the impedance of the circuit or circuits used.

The secondary self-inductive impedance is the joint impedance of all the secondary circuits, that is one-third the impedance per secondary circuit with three-phase, or one-half with two-phase wound secondary or armature.

3rd. In the single phase motor the characteristic constant: $\vartheta = 2yz$ is twice that of the same motor on polyphase circuit and the behavior of the motor thus correspondingly poorer.

3. While the load curve of the single-phase motor calculated in this way gives a fair agreement with the test at or near synchronism, at intermediate and low speeds, especially with motors of high magnetizing current, as high-frequency motors, experience shows that a more accurate investigation of the internal reactions of the motor is necessary; and in view of the rapid introduction of self-starting single-phase induction motors, in which the range of torque curve from standstill upward is of importance, the results of this investigation will be given in the following:

Primary Admittance.—At synchronism the armature or secondary of the single-phase induction motor is not without current, but carries the exciting current of the quadrature magnetic flux. The primary thus carries a current equal to the secondary exciting current or exciting current of the quadrature flux (reduced to the primary by the ratio of turns) plus the exciting current of the main magnetic flux. Thus if Y_0^1 = exciting admittance of the main magnetic flux, at synchronism, where main flux and quadrature flux are equal, the secondary exciting admittance or admittance of the exciting current in the secondary of the motor is $Y_1^1 = Y_0^1$, the total exciting admittance thus $Y^1 = Y_0^1 + Y_1^1 = 2\,Y_0^1$.

At standstill in the absence of a starting device, the quadrature flux and thus the secondary exciting current have disappeared. If a starting device is used which impresses upon the motor at standstill an auxiliary quadrature flux $\Phi_1 = t\,\Phi_0$, where Φ_0 = main magnetic flux, the secondary or quadrature exciting current at standstill corresponds to Φ_1, that is, is t times the exciting current of the main magnetic flux, and the total exciting current thus $(1+t)$ times that of the main magnetic flux.

Thus the two magnetic fluxes can either be considered separately, the main magnetic flux corresponding to a counter E. M. F. e equal impressed E. M. F. less impedance voltage (in its proper phase relation) giving the primary exciting current $e Y_0^1$, and the quadrature magnetic flux corresponding to a counter E. M. F. e^1, varying from e at synchronism to $t\,e$ at standstill, and giving the secondary exciting current $e^1 Y_0^1$, varying from $e Y_0^1$ at synchronism to $e\,t\,Y_0^1$ at standstill; or both magnetic fluxes can be considered together as produced by the counter E. M. F., e equal to the impressed E. M. F. less impedance drop, but the main magnetic flux as having a constant admittance Y_0^1, and the quadrature magnetic flux an admittance varying from Y_0^1, at synchronism to $t\,Y_0^1$ at standstill (or 0, if at standstill no quadrature magnetic flux exists). The latter method is the more convenient and thus preferred in the following.

The function, in which the secondary exciting admittance varies between standstill and synchronism, depends upon the nature of the starting device, and is in the absence of a starting device and with the monocyclic starting device and the condenser in the tertiary circuit, an elliptic function of slip, but can as first approximation be assumed as proportional to the slip, that is as linear function. The secondary exciting admittance at slip s is then: $Y_1^1 = Y_0^1\,[1-(1-t)s]$ in a motor whose starting device produces at standstill a ratio of fluxes t. The total exciting admittance at slip s is thus: $Y^1 = Y_0^1 + Y_1^1 = Y_0^1\,(2-s)$ or $Y^1 = Y_0^1 + Y_1^1 = Y_0^1\,[2-(1-t)s]$ respectively.

4. *Self-Inductive Impedance.*—At synchronism the secondary impedance of the single-phase motor is the joint impedance of all secondary circuits, that is one-third the impedance per circuit with a three phase, one-half the impedance per circuit with a two-phase armature, since all secondary circuits uniformly correspond to the primary circuit. At standstill, however, the secondary circuits correspond to the primary circuit only with their projection upon the plane perpendicular to the main magnetic flux, that is as far as interlinked with the primary flux. That is, the resultant secondary impedance at standstill equals

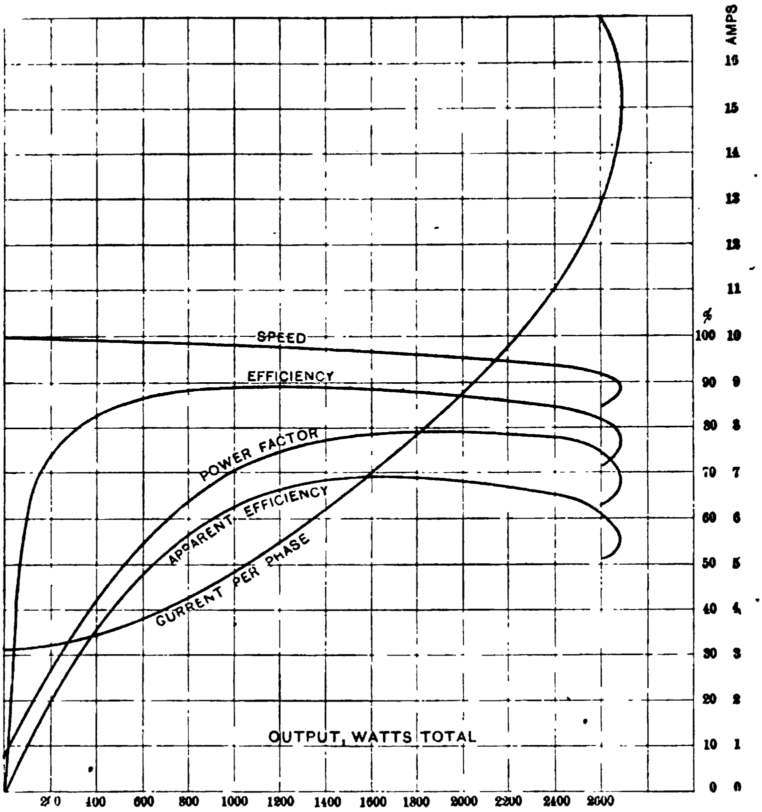


FIG. 1. Load Curves of Three-Phase Motor.

$$e_0 = 110.$$
$$Y_0 = .002 + .03 j.$$
$$Z_0 = .6 - 2.4 j.$$
$$Z_1 = .6 - 2.4 sj.$$

one-half the joint impedance of all secondary circuits. Thus from standstill to synchronism the secondary impedance of the single-phase motor with a three-phase secondary of impedance Z_1 per circuit varies from $\frac{2}{3}\,Z_1$ at standstill to $\frac{1}{3}\,Z_1$ at synchronism. With two-phase secondary of impedance Z_1 per circuit it varies from Z_1 at standstill to $\frac{1}{2}\,Z_1$ at synchronism, and as first approximation the resultant secondary impedance of the single-phase motor can be expressed as function of the slip s:

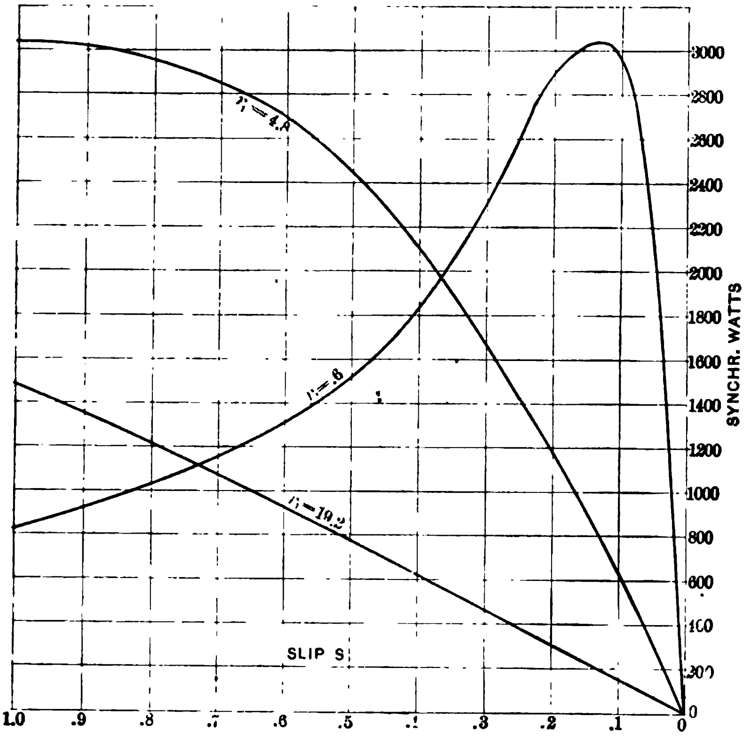


FIG. 2. Load Curves of Three-Phase Motor.

Torque.

$e_0 = 110.$

$Y_0 = .002 + .03\,j.$

$Z_0 = .6 - 2.4\,j.$

$$Z_1 = \left.\begin{array}{r} .6 - \\ 4.8 - \\ 19.2 - \end{array}\right\} 2.4\,sj.$$

$$Z_1^1 = Z_1\,\frac{1+s}{3}$$

in a three-phase secondary with impedance Z_1 per circuit.

$$Z_1^1 = Z_1 \frac{1+s}{2}$$

in a two-phase secondary with impedance Z_1 per circuit.

5. The primary self-inductive impedance is that of the circuits used. Thus in a three-phase motor of impedance Z_0 per primary delta circuit, when connected with two of its terminals to single-phase mains, the primary single-phase impedance is $Z_0^1 = \frac{2}{3} Z_0$ (since two sides of the triangle are in series with each other but in shunt with the third side). In a two-phase motor of impedance Z_0 per circuit, with one circuit used on single-phase mains, the primary single-phase impedance is Z_0.

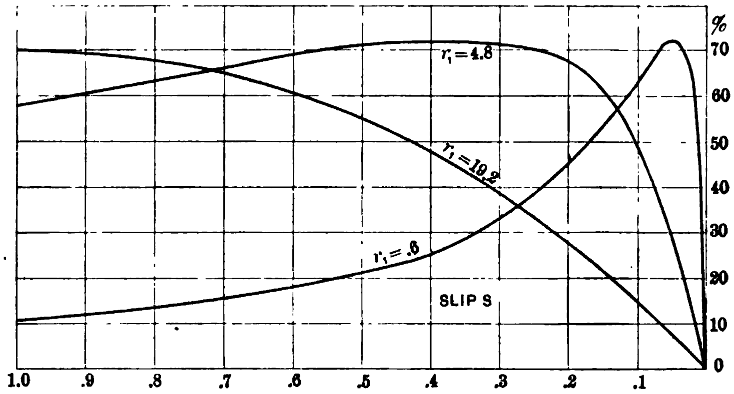


FIG. 3. Speed Curves of Three-Phase Motor. Apparent Torque Efficiency.

$$e_0 = 110.$$
$$Y_0 = .002 + .08j.$$
$$Z_0 = .6 - 2.4j.$$
$$Z_1 = \left.\begin{matrix} .6 - \\ 4.8 - \\ 19.2 - \end{matrix}\right\} 2.4\,sj.$$

The characteristic constant of the single-phase induction motor, or the product of exciting admittance at synchronism times total impedance at standstill, or approximately of exciting current over starting current, or of useful flux over waste flux, is twice that of the same motor on polyphase circuit, since in the three-phase motor the admittance is trebled, the impedance reduced to two-thirds; in the two-phase motor the admittance is doubled and the impedances are the same on single-phase as on polyphase circuit.

6. As instances are shown in Fig. 1 the load curves and in Figs. 2 and 3 the speed curves of a three-phase motor of the constants per delta circuit.

Impressed E. M. F.: $e_0 = 110.$

Exciting admittance: $Y_0 = .002 + .03\,j.$

Primary self-inductive impedance: $Z_0 = .6 - 2.4\,j.$

Secondary self-inductive impedance: $Z_1 = .6 - 2.4\,j.$

Thus: Total impedance: $Z = Z_0 + Z_1 = 1.2 - 4.8\,j.$

$$z = 4.948$$

$$y_0 = .03007.$$

Thus the characteristic constant $\vartheta = y_0\,z = .149.$

The same motor as single-phase motor, connected with two of its terminals to the single-phase mains, and without starting device, has the constants:

Primary exciting admittance: $Y_0^1 = .003 + .045\,j.$

Secondary exciting admittance: $Y_1^1 = (1 - s)\,(.003 + .045\,j.)$

Primary self-inductive impedance: $Z_0^1 = .4 - 1.6\,j.$

Secondary self-inductive impedance: $Z_1^1 = (1 + s)\,(.2 - .8\,j.)$

Thus at synchronism: $Y^1 = Y_0^1 + Y_1^1 = .006 + .09\,j.$

$$y^1 = .0902.$$

At standstill: $Z^1 = Z_0^1 + Z_1^1 = .8 - 3.2\,j.$

$$z^1 = 3.30.$$

Thus the characteristic constant $\vartheta = y^1\,z^1 = .298.$

The torque is $T = e^2\,a_1\,(1 - s).$

This motor fairly represents what can be done in a 1 K.W. 125-cycle single-phase motor. Its load curves are shown in Fig. 4 and the speed curves in Fig. 5. These curves are calculated in the way shown in my previous paper, with Y^1 as exciting admittance and Z_0^1 and Z_1^1 as self-inductive impedances, except that these quantities here are functions of the slip s, and not constants as assumed in my previous paper.

II.—CONDENSER IN TERTIARY CIRCUIT.

7. The efficiency of the single-phase induction motor, while inherently lower than that of the same motor on polyphase circuit, is with better motors still quite fair. Very low, however, especially at light loads is the power factor, and thus the apparent efficiency, due to the primary circuit carrying the magnetizing current of both magnetic circuits. This is the more objectionable as single-phase circuits are mostly of high frequency, and the high-frequency induction motor has inherently a higher magnetizing current, in consequence of the lesser pitch

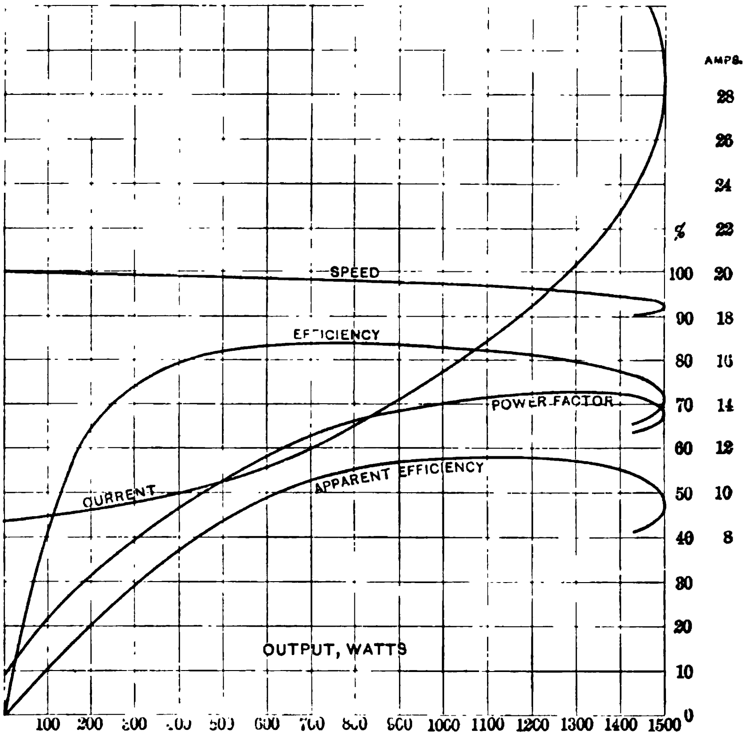


FIG. 4. Load Curves of Single-Phase Motor.

$$e_0 = 110.$$
$$Y_0^1 = .003 + .045j.$$
$$Y_1^1 = (1 - s)(.003 + .045j.)$$
$$Z_0^1 = .4 - 1.6j.$$
$$Z_1^1 = (1 + s)(.2 - .8j).$$

per pole, and thus lesser number of ampere-turns available in the motor field. This and the excessive current required with most starting devices, to get any noticeable starting torque, have thus far been the most serious objections to the introduction of the single-phase induction motor.

To improve the power factor, which as seen, in the motor in Fig. 4, reaches only 71% at full load and 53% at half load, condensers shunted across the motor terminals have been proposed, but have not been successful, for the following reasons:

At best the shunted capacity compensates for the lagging currents in the single-phase supply circuit only, but the excessive magnetizing current still exists in the motor circuits, causing a decrease of output, etc. In most of the high-frequency circuits existing to-day shunted capacity fails, however, entirely to reduce the current taken by a single-phase motor. To do this it is necessary that the E. M. F. wave of the generator resembles a sine wave with extreme closeness. This is not the case in most high-frequency systems, and is not desirable either, since the saw-tooth wave of the uni-tooth alternator, generally preferred, gives from 8 to 12% less hysteresis loss in the transformers than the sine wave, and thus a correspondingly higher all-day efficiency of the system.

On such circuits with saw-tooth E. M. F. waves the condenser, while taking away the wattless lagging current, adds triple and quintuple frequency currents of the same or even greater magnitude, and thus does not raise but may even lower the power factor and the apparent efficiency.

Thus in the three-phase motor in Fig. 1, at 1500 watts output, the power factor is 78%, the current 6.6 amperes at 110 volts, hence:

$$\mathbf{I}_0 = 5.15 + 4.13\,j$$

and, to compensate for the lagging current, a condenser susceptance would be required:

$$k = \frac{4.13}{110} = .0375$$

Assuming the wave shape of impressed E. M. F., $e_0 = 110$ as:

$$\mathbf{E}_0 = 107_1 + 10_3 + 20_5 - 10_7$$

the current input in the condenser of general susceptance:

$$Y = -.0375\, n\, j_n$$

is:

$$\mathbf{I}_k = 4.03\, j_1 - 1.13\, j_3 - 3.75\, j_5 + 2.63\, j_7$$

thus: the total current:

$$\mathbf{I} = \mathbf{I}_0 + \mathbf{I}_k$$

$$= (5.15 + .10\, j_1) - 1.13\, j_3 - 3.75\, j_5 + 2.63\, j_7$$

or, absolute:

$$I = 6.99 \text{ amperes}$$

thus the power factor:

$$p = \frac{5.15}{6.99} = 73.7\%$$

that is, in this case, by the use of shunted capacity with a distorted wave of E. M. F., the power factor of the motor is reduced from 78% to 73.7%, due to the appearance of higher harmonics of current.

8. Investigations extending over some years have led me to an arrangement whereby the condenser can be utilized in the single-phase induction motor to compensate for the lagging current not only in the supply circuit but also in the motor proper, and that independently of the wave shape of impressed E. M. F., by utilizing the quadrature magnetic flux induced in the motor at speed.

If in a single-phase induction motor on the field or primary member, a second coil is arranged in quadrature position with the primary coil, this coil is in non-inductive relation to the primary coil, but E. M. F. is induced therein with the motor at speed by the secondary or armature, that is, this auxiliary coil is a tertiary circuit which receives its E. M. F. by double transformation.

Since, however, primary, secondary and tertiary have multi-tooth or distributed windings, and the magnetic flux in the secondary member revolves at constant intensity and constant velocity, due to its closed circuits of low resistance, the E. M. F. induced in the tertiary is an absolute sine wave irrespective of the wave shape of the E. M. F. impressed upon the primary (as fully borne out by tests). Connecting to the tertiary coil a condenser of the same condenser admittance as the secondary exciting admittance, the tertiary condenser circuit gives the secondary magnetizing current, that is the secondary current becomes zero at synchronism, just as in a polyphase motor, and

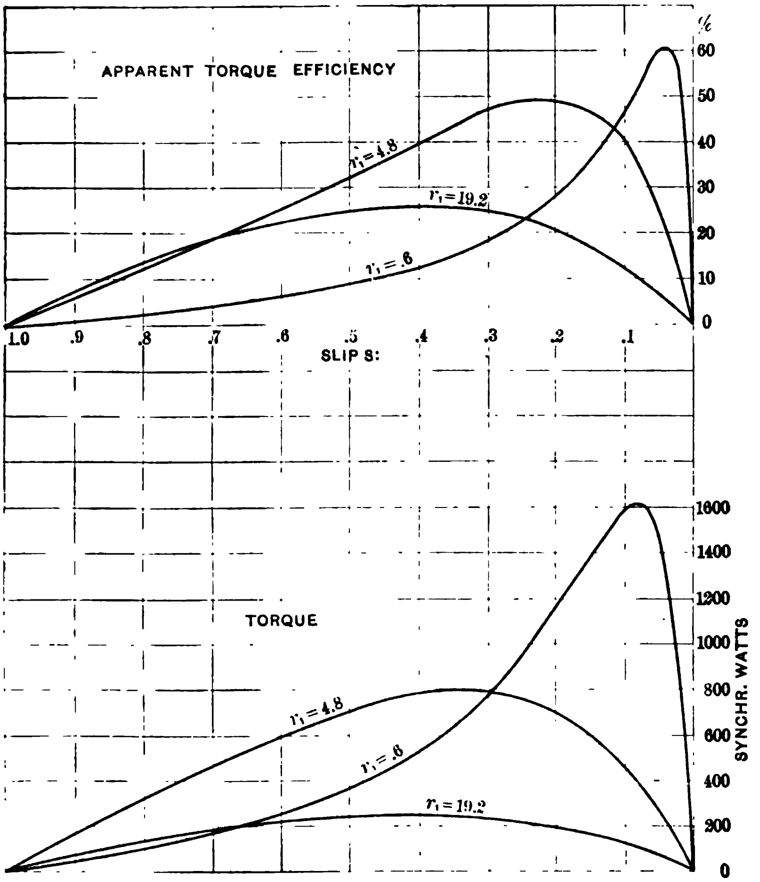


FIG. 5. Speed Curves of Single-Phase Motor.

$$e_0 = 110.$$

$$Y_0^1 = .003 + .045j.$$

$$Y_1^1 = (1 - s)(.003 + .045j.)$$

$$Z_0^1 = .4 - 1.6j.$$

$$Z_1^1 = (1 + s)\left(\begin{matrix}.2 -\\ 1.6 -\\ 6.4 -\end{matrix}\right\} 1.6\,sj.)$$

the primary current is reduced to the magnetizing current of the main magnetic flux only.

If twice this capacity is used, the condenser current in the tertiary circuit supplies the magnetization of the quadrature magnetic flux, and at the same time causes a current in the secondary to flow, which, carried by the rotation 90° or into alignment with the primary circuit, gives the primary magnetization also, so that in this case the primary magnetizing current entirely disappears, and the primary circuit carries energy current only, that is the total magnetization is given by the condenser in the tertiary circuit, or the motor has 100% power factor. This requires a volt-ampere capacity of the condenser equal to the total magnetizing volt-amperes of the motor.

As seen, this arrangement separates the energy supply, and the magnetization of the motor into two circuits and supplies the latter by condenser, and thus relieves primary mains and primary motor circuit of the lagging magnetizing current, thereby increases the maximum output of the motor, and brings the power factor up to unity, and at the same time uses the total circumference of the field structure, that is secures a greater economy of material.

9. The calculation of such a motor is as follows:

Let:

$Y_0^1 = g_0 + j\, b_0$ = primary exciting admittance.

$Y_1^1 = (1 - s)\, Y_0^1 = (1 - s)\,(g_0 + j\, b_0)$ = secondary exciting admittance, as discussed above.

$Z_0^1 = r_0 - jx_0$ = primary single-phase impedance.

$Z_1^1 = (1 + s)\,(r_1 - j\, s\, x_1)$ = secondary single-phase impedance.

$Z_2 = r_2 - j\, x_2$ = tertiary self-inductive impedance.

$Y_3 = g_3 - j\, b_3$ = condenser admittance, thus:

$Z_3 = r_3 + j\, x_3 = \frac{1}{Y_3}$ = condenser impedance, and

$Y_4 = \frac{1}{Z_2 + Z_3} = g_4 - j\, b_4$ = total admittance of tertiary circuit.

Where: s = slip.

Let, further:

e = E. M. F. induced by the mutual magnetic main flux at full frequency.

Thus, $(1 - s)\,e$ = induced quadrature E. M. F.

It is then, at slip s:

tertiary current:

$$\mathbf{I}_4 = e\,(1 - s)\,Y_4$$
$$= e\,(1 - s)\,(g_4 - j\,b_4)$$

secondary exciting current:

$$\mathbf{I}_{10} = e\,Y_1{}^1 = e\,(1 - s)\,(g_0 + j\,b_0)$$

secondary load current:

$$\mathbf{I}_1 = \frac{e\,s}{Z_1{}^1} = \frac{e\,s}{(1 + s)\,(r_1 - j\,s\,x_1)} = e\,(a_1 + j\,a_2)$$

where:

$$a_1 = \frac{s\,r_1}{(1 + s)\,(r_1{}^2 + s^2\,x_1{}^2)} \qquad a_2 = \frac{s^2\,x_1}{(1 + s)\,(r_1{}^2 + s^2\,x_1{}^2)}.$$

thus, total secondary current:

$$\mathbf{I}^1 = \mathbf{I}_1 + \mathbf{I}_{10} + \mathbf{I}_4$$

primary current:

$$\mathbf{I}_0 = \mathbf{I}^1 + e\,Y_0{}^1$$
$$= e\,(b_1 + j\,b_2)$$

where:

$$b_1 = a_1 + (2 - s)\,g_0 + (1 - s)\,g_4$$
$$b_2 = a_2 + (2 - s)\,b_0 - (1 - s)\,b_4$$

primary impressed E. M. F.:

$$\mathbf{E}_0 = e + Z_0{}^1\,\mathbf{I}_0$$
$$= e\,(c_1 + j\,c_2)$$

where:

$$c_1 = 1 + r_0\,b_1 + x_0\,b_2 \qquad c_2 = r_0\,b_2 - x_0\,b_1$$

thus:

$$e = \frac{e_0}{\sqrt{c_1{}^2 + c_2{}^2}} \text{ etc.}$$

torque:

$$T = e^2\,a_1\,(1 - s) \text{ etc.}$$

10. In practice the tertiary circuit is usually not arranged in quadrature position with the primary circuit, but under an angle of 60°, so as to give inthe moment of starting the same mutual in-

duction between primary and tertiary, and thereby induce at standstill an E. M. F. in the tertiary, which by causing a leading current in the condenser circuit, produces an auxiliary quadrature magnetic flux and thus makes the motor self-starting. At the same time, this arrangement offers the advantage of using the ordinary three-phase motor as singlephase condenser motor. It is shown in Fig. 6:

In a three-phase motor *M*, the terminals 1 and 2 are connected to the single-phase mains *a* and *b*, the terminals 1 and 3 to the condenser of admittance $Y^3 = g_3 - j\, b_3$. In this case the circuits 1–2 and 1–3–2 in multiple act as primary, and the circuits 1–3 and 1–2-3 in multiple as tertiary circuit. Since at present this arrangement, with either △ or Y connected motor field, is exclusively used, and any other arrangement can be investigated in an analogous manner, I shall in the following restrict the discussion thereto.

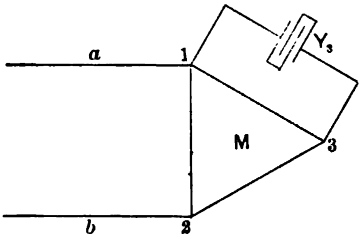


FIG. 6.

With a position angle of 60° the tertiary circuit is still so far distant electrically from the primary that at speed it is practically independent of the wave shape of primary impressed E. M. F., and no serious effect is produced in the condenser circuit by a distortion of the primary wave shape. That is, with the saw-tooth wave of the uni-tooth alternator the compensation for lagging currents by the condenser is still practically complete and the power factor unity.

III.—THEORY OF SINGLE-PHASE CONDENSER MOTOR WITH THREE-PHASE ARRANGEMENT OF CIRCUITS.

11. Let, in a three-phase wound induction motor:

$Z_0 = r_0 - j\, x_0$ = primary self-inductive impedance per motor delta circuit.

$Z_1 = r_1 - j\,x_1$ = secondary self-inductive impedance per circuit, reduced to primary

$Y_0 = g_0 + j\,b_0$ = primary exciting admittance, per motor delta circuit.

$Y_3 = g_3 - j\,b_3$ = admittance of condenser connected across motor terminals 1 and 3, Fig. 6 while motor terminals 1 and 2 are connected to the single-phase mains of E.M.F. e_0

On a three-phase system of E.M.F. e_0, it is, in starting, per motor circuit:

$$\mathbf{I}_1 = \frac{e}{r_1 - j\,x_1} = e\,(a_1 + j\,a_2) = \text{secondary current},$$

where:

$$a_1 = \frac{r_1}{r_1^2 + x_1^2} \qquad a_2 = \frac{x_1}{r_1^2 + x_1^2}$$

e = counter E.M.F. of motor.

$e\,Y_0 = e\,(g_0 + j\,b_0)$ = primary exciting current, thus:

$\mathbf{I}_0 = \mathbf{I}_1 + e\,Y_0 = e\,(b_1 + j\,b_2)$ = primary current,

where: $b_1 = a_1 + g_0 \qquad b_2 = a_2 + b_0$

thus, primary impressed E.M.F.:

$$\mathbf{E}_0 = e + Z_0\,\mathbf{I}_0 = e\,(c_1 + j\,c_2)$$

where: $c_1 = 1 + r_0\,b_1 + x_0\,b_2 \qquad c_2 = r_0\,b_2 - x_0\,b_1$

hence:

$$e = \frac{\mathbf{E}_0}{c_1 + j\,c_2}$$

and, absolute:

$$e = \frac{e_0}{\sqrt{c_1^2 + c_2^2}}$$

thus, total *stationary admittance*, per motor delta circuit:

$$Y = \frac{\mathbf{I}_0}{\mathbf{E}_0} = \frac{b_1 + j\,b_2}{c_1 + j\,c_2} = g + j\,b$$

where:

$$g = \frac{b_1\,c_1 + b_2\,c_2}{c_1^2 + c_2^2} \qquad b = \frac{b_2\,c_1 - b_1\,c_2}{c_1^2 + c_2^2}$$

the starting torque per circuit is:

$$T = e^2 a_1$$

$$= \frac{e_0^2 a_1}{c_1^2 + c_2^2}$$

thus, *total starting torque:*

$$T_\Delta = 3\,T = \frac{3\,e_0^2\,a_1}{c_1^2 + c_2^2}$$

12. Starting as single-phase condenser motor, it is, in Fig. 6:

admittance of circuit from terminal 1 to 3: $Y + Y_3$

let the E.M.F. across Y_3 be: $\mathbf{E}_3$

admittance of circuit from terminal 3 to 2: Y

the E.M.F.: $e_0 - \mathbf{E}_3$

thus, since the same current passes both circuits in series:

$$Y + Y_3 \div Y = e_0 - \mathbf{E}_3 \div \mathbf{E}_3$$

or:

$$\mathbf{E}_3 = \frac{e_0\,Y}{2\,Y + Y_3} = e_0\,(h_1 + j\,h_2)$$

where:

$$h_1 = \frac{g\,(2\,g + g_3) + b\,(2\,b - b_3)}{(2\,g + g_3)^2 + (2\,b - b_3)^2},\ h_2 = \frac{b\,(2\,g + g_3) - g\,(2\,b - b_3)}{(2\,g + g_3)^2 + (2\,b - b_3)^2}$$

and, absolute:

$$e_3 = e_0\,\sqrt{h_1^2 + h_2^2}$$

thus, the ratio of condenser E.M.F. to main E.M.F., at standstill:

$$h = \frac{e_3}{e_0} = \sqrt{h_1^2 + h_2^2}$$

The quadrature component of E.M.F. which gives the auxiliary quadrature or starting magnetic flux, is thus:

$$E_3^j = e_0\,h_2$$

In the three-phase motor, at equality of the main and the quadrature fluxes, the quadrature flux is, as altitude of the equilateral triangle:

$$E^{j} = \frac{e_0 \sqrt{3}}{2}$$

Thus, with single-phase condenser motor, in starting the ratio of auxiliary quadrature to main magnetic flux is:

$$t = \frac{E_3^{j}}{E^{j}} = \frac{2\, h_2}{\sqrt{3}} = 1.155\, h_2$$

and thus the *starting torque:*

$$T_0 = t\, T_{\triangle} = 1.155\, h_2\, T_{\triangle}$$

Since, in the circuit from terminal 3 to 2 the admittance $= Y$, the E. M. F. $e_0 - \mathbf{E}_3$, it is:
Current taken by the condenser motor in starting:

$$\mathbf{I}_0 = e_0\, Y + (e_0 - E_3)\, Y$$

$$= \frac{e_0\, Y\, (3\, Y + 2\, Y_3)}{2\, Y + Y_3}$$

13. Running as single-phase condenser motor, it is, denoting the counter E. M. F. of the main magnetic circuit at slip s by e:
secondary impedance:

$$Z_1^1 = \frac{Z_1}{3}\,(1 + s) = \frac{1 + s}{3}\,(r_1 - j\, s\, x_1)$$

primary impedance:

$$Z_0^1 = \tfrac{2}{3}\, Z_0 = \tfrac{2}{3}\,(r_0 - j\, x_0)$$

primary exciting admittance:

$$Y_0^1 = 1.5\, Y_0 = 1.5\,(g_0 + j\, b_0)$$

secondary exciting admittance:

$$Y_1^1 = 1.5\, Y_0\, [1 - (1 - t)\, s]$$

since for: $s = 1$, the secondary exciting admittance must be: $Y_1^1 = t\, Y_0^1$, t being the ratio of quadrature flux to main flux.
condenser admittance:

$$Y_3 = g_3 - j\, b_3$$

self-inductive impedance of tertiary circuit:

$$Z_2 = \tfrac{2}{3}\,Z_0 = \tfrac{2}{3}\,(r_0 - j\,x_0)$$

thus, total admittance of tertiary condenser circuit:

$$Y_4 = \frac{1}{Z_2 + \frac{1}{Y_3}} = g_4 - j\,b_4$$

The E. M. F. acting upon the condenser admittance Y_3 drops with increasing slip, from e_0 at $s = O$ to $e_3 = e_0\,h$ at $s = 1$, thus is at slip s, approximately:

$$e_0\,[1 - (1 - h)\,s]$$

or inversely, assuming upon the condenser circuit instead of the induced E. M. F. $e_3{}^1$ of this circuit, the main induced E. M. F. e acting, the admittance has to be reduced in the proportion

$$\frac{e_3{}^1}{e},$$

that is, the apparent admittance of the condenser circuit at slip s, or admittance reduced to induced E. M. F. e, is:

$$Y_4{}^1 = Y_4\,[1 - (1 - h)\,s]$$

14. The calculation of the motor is now as follows: secondary load current:

$$\mathbf{I}_1 = \frac{s\;e}{Z_1\;s} = \frac{3\;s\;e}{(1 + s)\,(r_1 - j\;s\,x_1)} = e\,(a_1 + j\;a_2)$$

secondary exciting current:

$$\mathbf{I}_1{}^1 = e\;Y_1{}^1 = 1.5\;e\;Y_0\,[1 - (1 - t)\,s]$$

secondary condenser current:

$$\mathbf{I}_4 = e\;Y_4{}^1 = e\;Y_4\,[1 - (1 - h)\,s]$$

thus, total secondary current:

$$\mathbf{I}^1 = \mathbf{I}_1 + \mathbf{I}_1{}^1 + \mathbf{I}_4$$

primary exciting current:

$$\mathbf{I}_0{}^1 = e\;Y_0{}^1 = 1.5\;e\;Y_0$$

thus, total primary current:

$$\begin{aligned} \mathbf{I}_0 &= \mathbf{I}^1 + \mathbf{I}_0^1 \\ &= \mathbf{I}_1 + \mathbf{I}_4 + \mathbf{I}_1^1 + \mathbf{I}_0^1 \\ &= e\,(b_1 + j\,b_2) \end{aligned}$$

primary impressed E. M. F.:

$$\begin{aligned} \mathbf{E}_0 &= e + Z_0^1\,\mathbf{I}_0 \\ &= e\,(c_1 + j\,c_2) \end{aligned}$$

thus, main counter E. M. F.:

$$e = \frac{\mathbf{E}_0}{c_1 + j\,c_2}$$

or:

$$\mathbf{E} = \frac{e_0}{c_1 + j\,c_2}$$

and, absolute:

$$e = \frac{e_0}{\sqrt{c_1^2 + c_2^2}}$$

hence, primary current:

$$\mathbf{I}_0 = \frac{e_0\,(b_1 + j\,b_2)}{c_1 + j\,c_2} \qquad I_0 = e_0\sqrt{\frac{b_1^2 + b_2^2}{c_1^2 + c_2^2}}$$

volt-ampere input:

$$Q_0 = e_0\,I_0$$

power input:

$$P_0 = [\mathbf{I}_0\,e_0]^1 = e_0^2\,\frac{b_1\,c_1 + b_2\,c_2}{c_1^2 + c_2^2}$$

Fictitious torque (that is, torque, which would be given, if the quadrature flux equalled the main magnetic flux):

$$T^1 = e^2\,a_1 = \frac{e_0^2\,a_1}{c_1^2 + c_2^2}$$

At standstill, the torque must be:

$$T_0 = t\,T_{\triangle}$$

thus if:

$$T_0^1 = \left|\frac{e_0^2\,a_1}{c_1^2 + c_2^2}\right|_0 = \text{fictitious torque at standstill,}$$

denoting:

$$\frac{T_0}{T_0'^1} = \left| \frac{t\,T_\Delta}{\frac{c_0^2\,a_1}{c_1^2 + c_2^2}} \right|_0 = v$$

it is:

torque at slip s:

$$T = T^1\left[1 - (1 - v)\,s\right]$$

$$= \frac{e_0^2\,a_1}{c_1^2 + c_2^2}\left[1 - (1 - v)\,s\right]$$

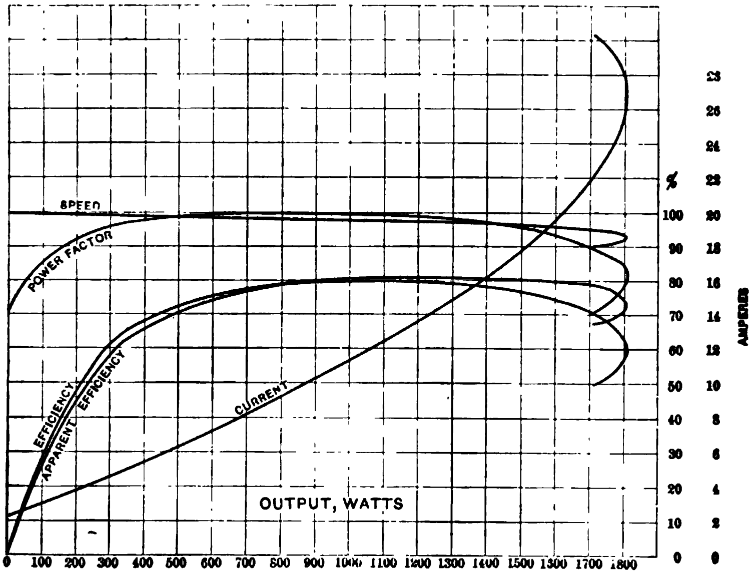


FIG. 7. Load Curves of Single-Phase Condenser Motor.

$$e_0 = 110$$

$$Y_0{}^1 = .008 + .045\,j.$$

$$Y_1{}^1 = (1 - .947\,s)\,(.003 + .045\,j.)$$

$$Z_0{}^1 = .4 - 1.6\,j.$$

$$Z_1{}^1 = (1 + s)\,(.2 -- .8\,sj.)$$

$$Y_4{}^1 = (1 - .37\,s)\,(.0086 - .105\,j.)$$

$$T = e^2\,a_1\,(1 - .903\,s.)$$

and, power output:

$$P = T\,(1 - s)$$

$$= \frac{e_0^2\,a_1}{c_1^2 + c_2^2}\,(1 - s)\left[1 - (1 - v)\,s\right]$$

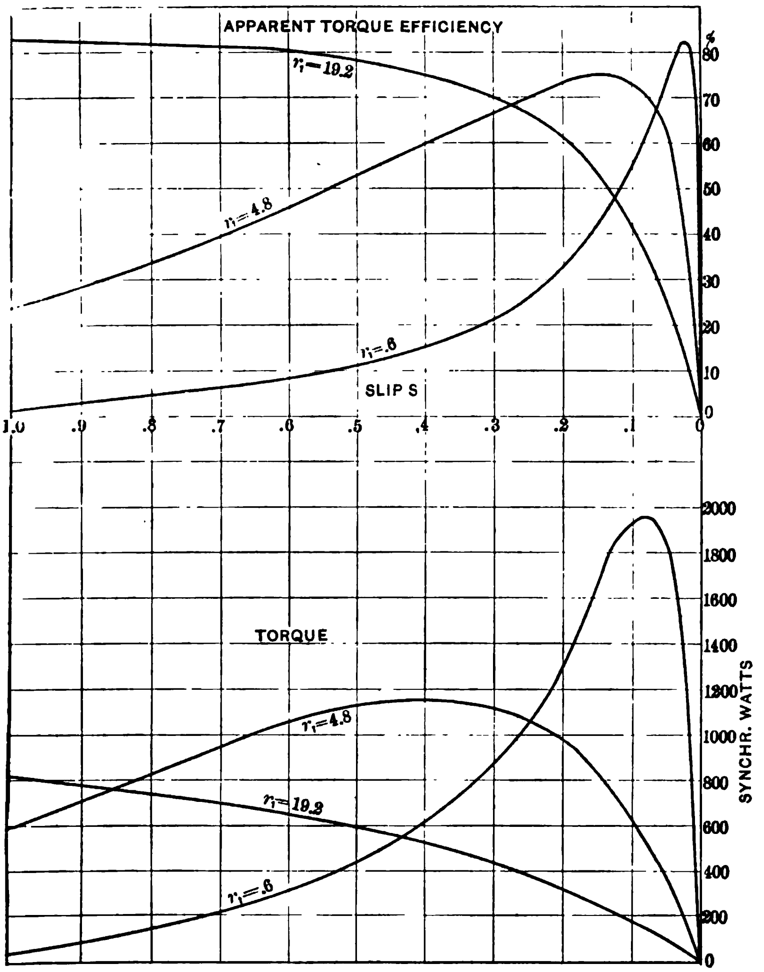


Fig. 8. Speed Curves of Single-Phase Condenser Motor.

$$e_0 = 110.$$

$$Y_0^1 = .003 + .045j.$$

$$\begin{array}{ll} Y_1^1 = (1 - & .947\,s \\ & .806\,s \\ & .448\,s)\,(.003 + .045\,j.) \end{array}$$

$$Z_0^1 = 4 - 1.6\,j.$$

$$Z_1^1 = (1 + s)\left(\left.\begin{array}{l} .2 - \\ 1.6 - \\ 6.4 - \end{array}\right\} 1.6\,s\,j.\right)$$

$$\begin{array}{ll} Y_4^1 = (1 - & .87\,s \\ & .39\,s \\ & .38\,s)\,(.0086 + .105\,j) \end{array}$$

$$\begin{array}{lll} & T & = e^2\,a_1\,(1 - .908\,s) \\ \text{Torque} & & \ e^2\,a_1\,(1 - .65\,s) \\ & & \ e^2\,a^1 \end{array}$$

And herefrom the efficiency, apparent efficiency, torque efficiency, apparent torque efficiency, and power factor.

As seen, before calculating the curves of the single-phase induction motor with condenser in the tertiary circuit, first the constants t, h, and v have to be calculated.

15. As an instance are shown in Figs. 7 and 8 the load and the speed curves of the motor given as three-phase motor in Figs. 1, 2, and 3, and as single-phase motor in Figs. 4 and 5, with a capacity slightly over-compensating for the exciting current so as to produce 100% power factor as intermediate load (about 1000 volt-amperes condensance).

In this motor, it is as three-phase motor:

$$Z_0 = .6 - 2.4\,j$$

$$Z_1 = .6 - 2.4\,j$$

$$Y_0 = .002 + .03\,j$$

As condenser admittance is assumed:

$$Y_3 = .003 - .09\,j$$

that is, an energy loss of 3.3% is assumed in the condenser and its compensator.

The speed curves in Figs. 2, 3, 5, and 8 are shown for short-circuited secondary: $r_1 = .6$ ohms, and also for resistances inserted in the secondary so as to give per secondary circuit the total resistance $r_1 = 4.8$ and: $r_1 = 19.2$ ohms.

It is then, at standstill as three-phase motor:

Three-phase:

$s = 1$ $e_0 = 110$

r_1:	I_0:	Y:	T_{Δ}:
.6	$5.4 + 22.4\,j$	$.049 + .204\,j$	825
4.8	$10.9 + 11.4\,j$	$.099 + .104\,j$	3030
19.2	$4.9 + 4.0\,j$	$.044 + .037\,j$	1480

In starting as single-phase condenser motor, it is:

$$Y_3 = .003 - .09\,j$$

thus:

r_1:	$\frac{Y}{2Y+Y_3}=h_1+jh_2$:	$t=1.155\ h_2$:	$h=\sqrt{h_1^2+h_2^2}$:	$T_0=tT_\Delta$
.6	$.63+.046j$	.053	.630	44
4.8	$.59+.168j$	.194	.613	590
19.2	$.40+.477j$	.552	.623	820

At standstill as single-phase condenser motor, for $s = 1$, it is:

$$Y_4 = .0086 - .105j$$

thus:

Z_1^1:	Z_0^1:	Y_0^1:	$Y_1^1 = t\ Y_0^1$:
$.4 - 1.6j$	$.4 - 1.6j$	$.003 + .045j$	$.00016 + .0024j$
$3.2 - 1.6j$	$.4 - 1.6j$	$.003 + .045j$	$.0005 + .0087j$
$12.8 - 1.6j$	$.4 - 1.6j$	$.003 + .045j$	$.0017 + .025j$

$Y_4^1 = h\ Y_4$:	$T_0^1 = e^2 a_1$:	$v = \frac{T_0}{T_0^1}$
$.0054 - .066j$	455	.097
$.0053 - .064j$	1685	.35
$.0054 - .065j$	820	1.00

and herefrom the motor is calculated, as explained above.

16. Comparing now the load curves of the motor under the three conditions of running, we see that as condenser motor on single-phase circuit the maximum output, 1810 watts, is higher than as ordinary single-phase motor, 1500 watts, but still very much less than as three-phase motor, 2680 watts. The slip at maximum output point is the same in the condenser motor as in the single-phase motor but less than in the three-phase motor. As single-phase motor the power factor, with a maximum of 73%, is less than as three-phase motor, with a maximum of 79%. As condenser motor, however, the power factor starts with .71.3% at standstill, reaches 100% at 800 watts and then decreases again to 90% at 1700 watts. In the total range from 260 watts to 1510 watts output the power factor is above 95%, that is practically unity. Below 800 watts output the current is leading, above it is lagging. In consequence of the high-power factor the apparent efficiency, that is the output per volt-ampere input is higher in the condenser motor than even in the three-phase motor, reaching a maximum of 80% in the former, and of only 69% in the latter. The efficiency is slightly less in the condenser motor, with a maximum of 81%, than in the single-phase

motor with 84% maximum. This is due to the energy loss in the condenser, or rather the compensator feeding the condenser (since with a 110-volt motor a compensator is required to bring the voltage at the condenser up to 500 volts as the minimum practicable in condenser). In the three-phase motor the efficiency is considerably higher, with 89% maximum.

It must be considered here, however, that these efficiencies, as in my previous paper, do not include the friction loss of the motor, which, depending upon the individual conditions of the motor, as number of poles, speed, etc., cannot be included in a general theory; and the outputs given are thus output at the secondary conductors, or mechanical output plus friction.

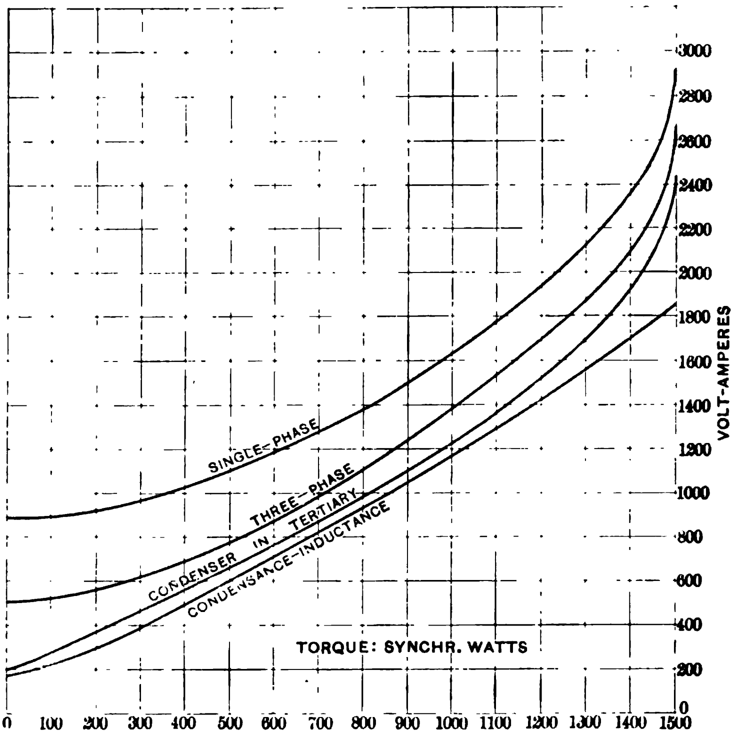


FIG. 9. Torque Curves.

Single-phase, $e_0 = 106$.
Three-phase, $e_0 = 77.5$
Single-phase, Condenser in Tertiary, $e_0 = 96$
Single-phase, Condensance-Inductance,, e_0 77.5

Especially interesting is the current running light, or exciting current, which in the three-phase motor is 39.8% of the current at two-thirds maximum output, in the single-phase motor is 55.7%, but in the condenser motor only 17.4% of the current at two-third maximum output, which can approximately be considered as the proper full load rating. Figs. 2, 3, 5, and 8 show the torque and the apparent torque efficiency, that is the torque per volt-ampere input, as function of the speed of the motor. As seen, the condenser motor takes an intermediate position between the three-phase and the single-phase motor. In the three-phase motor the maximum torque remains the same with increase of the secondary resistance, and the total torque curve merely shifts towards lower speed, the slip increasing proportional to the armature resistance. In the single-phase motor the maximum torque not only shifts towards lower speeds with increase of armature resistance, but falls off proportional to the slip, and thus rapidly becomes insignificant. In the condenser motor the falling off of the maximum torque, with increasing slip, by the introduction of secondary resistance, is much less, and the torque curves resemble more those of a three-phase

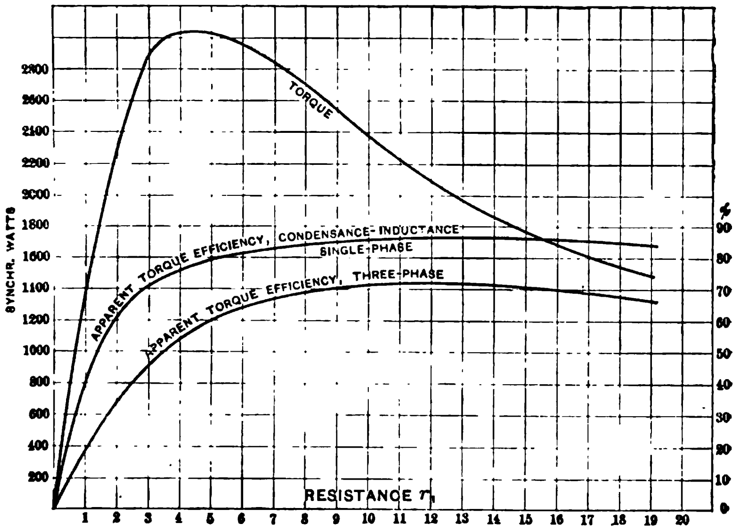


FIG. 10. Resistance Curves of Three-Phase Motor and Condensance-Inductance Single-Phase Motor.

$e_0 = 110$

motor. Obviously the effect of the condenser on the starting torque is greatest with high secondary resistance, where the condenser current gets nearer in magnitude to the current taken by the motor proper. Especially interesting are the curves of apparent torque efficiency. While they fall off rapidly with the speed in the single-phase motor, they remain high in the condenser motor and the apparent torque efficiency of the latter, even in starting, is higher than with the three-phase motor. That is, with resistance in the secondary, the single-phase motor with condenser in the tertiary circuit can give a larger starting torque per volt-ampere input than the same motor as polyphase motor.

This latter feature is still better shown in Fig. 9, where with the torque as abscissæ the volt-amperes input are plotted as ordinates, the voltage at the motor being assumed as reduced to

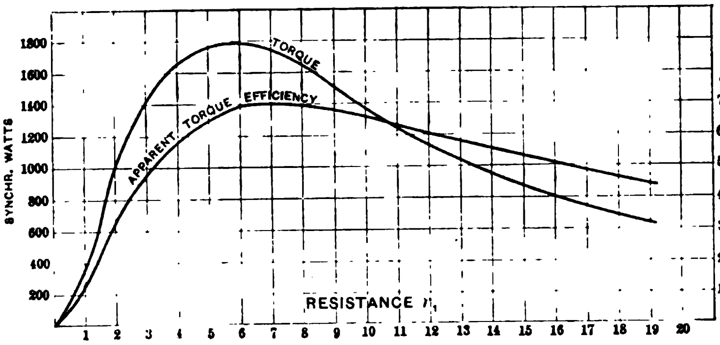


FIG. 11. Resistance Curves of Single-Phase Condenser Motor.

$$e_0 = 110$$
$$Y_3 = .0034 - .2j$$

such a value as to give the same maximum torque of 1500 synchronous watts in all motors. This would require for the three-phase condition of operation 77.5 volts, single-phase 106 volts, and for the condenser motor 96 volts. These curves show that for any torque and especially for small values of torque, or light loads, the condenser motor takes the least, the single-phase motor the most volt-ampere input.

Curves 8 show, however, that while it is undesirable, with polyphase motors, to start with a short-circuited armature, that is, no rheostatic control, wherever any considerable starting torque is required, due to the excessive starting current required under these conditions, this is still more the case with the condenser motor.

17. The variation of starting torque with the armature resistance is shown for the three-phase motor and for the condenser motor in Figs. 10 and 11, as calculated from the equations.

As seen, in both forms of motor with increase of resistance the starting torque increases, reaches a maximum, and then decreases again. The maximum in the three-phase motor is higher, 3030 synchronous watts, at lower secondary resistance, $r_1 = 4.5$ ohms, than with the condenser motor, where the maximum torque of 895 synchronous watts occurs at $r_1 = 6$ ohms. The apparent torque efficiency or starting torque per volt-ampere input reaches a maximum in the three-phase motor at far higher resistance than the torque and is 72% at 12 ohms. In the condenser motor the maximum of apparent torque efficiency is 70.5%, and nearer the maximum torque, at 7 ohms. For the latter motor the starting conditions are calculated for a constant capacity of $Y_3 = (.017 - j)\ .2$, that is higher capacity than chosen in the motor in Figs. 7 and 8.

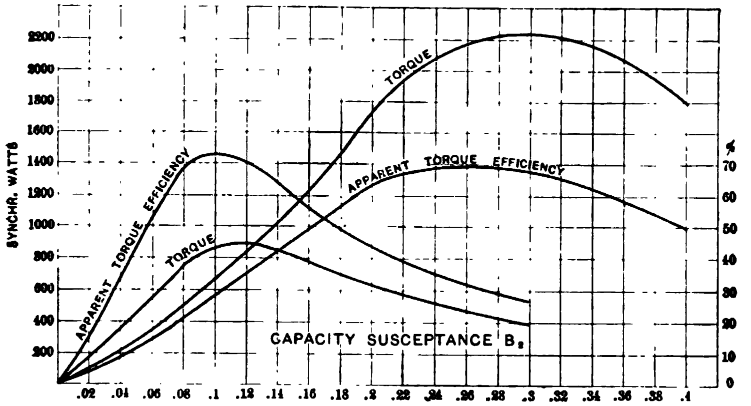


FIG. 12. Capacity Curves of Single-Phase Condenser Motor.

$$e_0 = 110$$

$$\begin{aligned} Y = {} & .099 + .104j \\ & .044 + .087j \end{aligned}$$

The effect on the starting torque of the condenser motor, of a variation of capacity is shown in Fig. 12 for the secondary resistances: $r_1 = 4.8$ and: $r_1 = 19.2$. As seen with the increase of capacity, in either case starting torque and apparent torque efficiency increase, reach a maximum, and then decrease again. With higher armature resistance: $r_1 = 19.2$, the maximum starting torque is at $Y_3 = (.017 - j)\ .12$, and is 890 synchronous watts; with lower armature resistance: $r_1 = 4.8$, it is 1615 synchronous watts at $Y_3 = (.034 - j)\ .3$.

The cause of the falling off of the starting torque if the capacity is increased beyond a certain value is the decreasing voltage at the condenser. With the increase of capacity the total impedance of circuit 1-3 in Fig. 10 and thus the voltage decreases again, the circuit approaching the condition of short-circuit.

18. As seen in the preceding, the starting torque of the single-phase induction motor with condenser in the tertiary circuit depends upon the secondary resistance and upon the capacity, and for every value of capacity a certain secondary resistance exists, and inversely for every value of secondary resistance a certain capacity, which gives a maximum starting torque.

These values of secondary resistance and of capacity which give maximum starting torque can approximately be calculated as follows:

Let: $Z_0 = r_0 - j\,x_0$ = primary self-inductive impedance,

$Z_1 = r_1 - j\,x_1$ = secondary self-inductive impedance.

Then: $Z = Z_0 + Z_1 = r - j\,x$, is approximately the total impedance, and

$$Y = \frac{1}{Z} = g + j\,b = \frac{1}{r - j\,x}$$

is the total admittance of the motor at standstill.

Hereby the exciting current of the motor is neglected, which essentially amounts to assuming it as shunt to the total circuit instead of as shunt between primary and secondary circuit.

If E_0 = impressed E. M. F., the counter E. M. F. is

$$E = E_0 \sqrt{\frac{r_1^2 + x_1^2}{r^2 + x^2}}$$

Neglecting the energy coefficient of the starting condensers, their admittances can be represented by:

$$Y_3 = -2\,j\,k$$

From the preceding calculation, the E. M. F. across the condenser is:

$$\mathbf{E}_3 = e_0 A,$$

where:

$$A = \frac{Y}{2\,Y + Y_3} = \frac{1}{2\left\{1 + \frac{Y_3}{2\,Y}\right\}} = \frac{1}{2\,(1 - k\,x - j\,k\,r)}$$

and the quadrature component of A is thus:

$$h_2 = \frac{k\,r}{2\,[(1 - k\,x)^2 + k^2\,r^2]}$$

the torque of the motor on three-phase circuit is:

$$T_\varDelta = 3\,e^2\,a_1 = \frac{3\,e^2\,r_1}{r_1^2 + x_1^2}$$

thus, substituted for e:

$$T_\varDelta = \frac{3\,e_0^2\,r_1}{r^2 + x^2}$$

and hence, the starting torque of the single-phase motor:

$$T = \frac{2}{\sqrt{3}}\,h_2\,T_\varDelta = \frac{\sqrt{3}\,e_0^2\,k\,r\,r_1}{(r^2 + x^2)\,[(1 - k\,x)^2 + k^2\,r^2]}$$

$$= \frac{\sqrt{3}\,e_0^2\,k\,r_1^2}{(r^2 + x^2)\,[(1 - k\,x)^2 + k^2\,r^2]}\left\{1 - \frac{r_0}{r}\right\}$$

Let
$$f = \frac{T}{\sqrt{3}\,e_0^2} = \frac{k\,r\,r_1}{(r^2 + x^2)\,[(1 - k\,x)^2 + k^2\,r^2]}$$

$$= \frac{k\,r^2}{(r^2 + x^2)\,[(1 - k\,x)^2 + k^2\,r^2]}\left\{1 - \frac{r_0}{r}\right\}$$

or, approximately:

$$f = \frac{k\,r^2}{(r^2 + x^2)\,[(1 - k\,x)^2 + k^2\,r^2]}$$

The maximum starting torque, at given capacity k, as function of resistance r is determined by:

$$\frac{\delta f}{\delta r^2} = 0$$

which, expanded, gives:

$$x^2 (1 - k x)^2 - k^2 r^4 = 0$$

$$r = \frac{\sqrt{\pm x (1 - k x)}}{k} = \sqrt{\mp (x^2 - x/k)}$$

substituting these values of r into T, it is:

$$(1) \quad T_1 = \sqrt{3}\, e_0 \, k \left(1 - \frac{r_0}{r}\right) = \sqrt{3}\, e_0^2 \, k \left(1 - \frac{r_0}{\sqrt{x/k - x^2}}\right)$$

$$(2) \quad T_2 = \frac{\sqrt{3}\, e_0^2 \, k \left(1 - \frac{r_0}{r}\right)}{(2 k x - 1)^2} = \frac{\sqrt{3}\, e_0^2 \, k}{(2 k x - 1)^2} \left(1 - \frac{r_0}{\sqrt{x^2 - x/k}}\right)$$

The value of k giving maximum torque is found by:

$$(1) \qquad \frac{\delta T_1}{\delta k} = 0$$

or, expanded:

$$\left(\frac{1}{k} - x\right) = \frac{r_0}{x} \left(\frac{3}{2 k} - x\right)^2$$

which gives the approximate solution, by substituting in the right hand side:

$$\frac{1}{k} = x:$$

$$\frac{1}{k} = x + \sqrt[3]{\frac{r_0^2 \, x}{4}}$$

Instance: $e_0 = 110$

$x = 4.8 \qquad r_0 = .6$

$$\frac{1}{k} = 5.556$$

$$r = \sqrt{\frac{x}{k} - x^2} = 1.905$$

$r_1 = 1.305$

$$Y_3 = -.36\,j$$

$$T_1 = 2580$$

(2)
$$\frac{\delta T_2}{\delta k} = 0$$

or, expanded:

$$\left(x - \frac{1}{k}\right)^3 = \frac{r_0^2}{4\,x}\left(2\,x - \frac{1}{k}\right)^2$$

which gives the approximate solution, by substituting in the right hand side: $1/k = x$:

$$\frac{1}{k} = x - \sqrt[3]{\frac{r_0^2\,x}{4}}$$

Instance:
$$e_0 = 110$$

$$x = 4.8 \qquad\qquad r_0 = .6$$

$$\frac{1}{k} = 4.044$$

$$r = 1.905$$

$$r_1 = 1.305$$

$$Y_3 = -.495\,j$$

$$T_2 = 1870$$

19. From the equation:

$$T = \frac{\sqrt{3}\,e_0^2\,k\,r\,r_1}{(r^2 + x^2)\,[(1 - k\,x)^2 + k^2\,r^2]}$$

the maximum starting torque, for a given value of secondary resistance r_1, and thus total resistance r, as function of the capacity k, is found thus.

Let:

$$\varphi = \frac{T\,(r^2 + x^2)}{\sqrt{3}\,e_0^2\,r\,r_1} = \frac{k}{(1 - k\,x)^2 + k^2\,r^2}$$

it is then:

$$\frac{\delta \varphi}{\delta k} = 0$$

expanded, this gives:

$$1 - k^2\,x^2 - k^2\,r^2 = 0$$

or:

$$k = \frac{1}{\sqrt{r^2 + x^2}}$$

substituted:

$$T_0 = \frac{\sqrt{3}\, e_0^2\, r\, r_1}{2\, z^2 (z - x)}$$

Instance:

$Z_0 = .6 - 2.4\,j$ $Z_1 = 4.8 - 2.4\,j / 19.2 - 2.4\,j$ $e_0 = 110$

thus: $Z = 5.4 - 4.8\,j / 19.8 - 4.8\,j$

$z = 1.225$ $/ 20.37$

$k = .1385$ $.049$

$Y_3 = -.277\,j$ $-.098\,j$

$T_0 = 2150$ 625

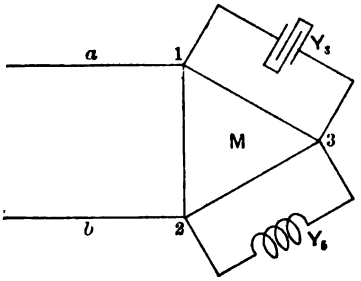


FIG. 18.

These values obviously are approximate only, for the reasons stated above.

IV. THREE-PHASE RELATION OF E. M. F.'S.

20. The starting torque of the three-phase wound single-phase induction motor can be increased far beyond the maximum value available by the use of capacity in the tertiary circuit, by shunting the third side of the motor triangle 3–2 by an admittance Y_5, which usually will have to be an inductance. By suitably varying the admittances Y_3 and. Y_5, the voltages across 1–3 and 3–2 can be maintained equal, and equal to the impressed voltage across 1–2, that is, a perfect three-phase triangle produced.

Let thus, in Fig. 13:

$Y_3 = g_3 - j\, b_3$ = condenser impedance shunted across circuit 1–3,

$Y_5 = g_5 + j\, b_5$ = inductive impedance shunted across circuit 3–2, and

$Y = g + j\, b$ = total impedance per motor delta circuit.

It is then :

Impedance of circuits : 1–3 : $Y + Y_3$

Impedance of circuits : 3–2 : $Y + Y_5$

Thus, if $\mathbf{E}_3$ = E.M.F. across 1–3, $\mathbf{E}_5$ = E.M.F across 3–2, it is :

$$\mathbf{E}_3 \div \mathbf{E}_5 = Y + Y_5 \div Y + Y_3$$

since the same current passes through both circuits in series.

The condition of exact three-phase relation of the three E.M.F.'s at the motor terminals is, that $\mathbf{E}_3$ and $\mathbf{E}_5$ are equal, and 120° displaced in phase, that is :

$$\frac{\mathbf{E}_3}{\mathbf{E}_5} = \cos 120° + j \sin 120°$$

$$= \frac{-1 + j\, \sqrt{3}}{2}$$

thus, substituted :

$$\frac{Y + Y_5}{Y + Y_3} = \frac{-1 + j \sqrt{3}}{2}$$

Assuming now the energy loss in the inductance Y_5 as 5%, that in the condensance Y_3 as 1.7%, it is :

$$Y_5 = b_5\, (.05 + j)$$

$$Y_3 = b_3\, (.017 - j)$$

Substituting these values, and $Y = g + j\, b$, in the equation :

$$\frac{Y + Y_5}{Y + Y_3} = \frac{-1 + j \sqrt{3}}{2}$$

separating the real and the imaginary components, and resolving, gives :

$$b_3 = 1.885\, g + .95\, b$$

$$b_5 = 1.836\, g - 1.012\, b$$

thus :

$$Y_3 = (.017 - j)\,(1.885\,g + .95\,b)$$

$$Y_5 = (.05 + j)\,(1.836\,g - 1.012\,b)$$

and, the total current input in the motor:

$$\mathbf{I}_0 = e_0\,Y + \frac{e_0}{2}\,(1 + j\,\sqrt{3})\,(Y + Y_3) = e_0\,Y + \frac{e_0}{2}\,(1 - j\,\sqrt{3})\,(Y + Y_5)$$

$$= e_0\,\left\{ (3.14\,g - .035\,b) + j\,(1.038\,b - .04\,g) \right\}$$

Neglecting, as approximation, the energy components of Y_3 and Y_5, it is:

$$Y_3 = -j\,b_3$$

$$Y_5 = j\,b_5$$

thus, substituted:

$$b_3 = g\,\sqrt{3} + b$$

$$b_5 = g\,\sqrt{3} - b$$

and:

$$\mathbf{I}_0 = e_0\,(3\,g + j\,b)$$

while in the three-phase motor the total current is:

$$\mathbf{I}_0 = 3\,e_0\,(g + j\,b)$$

that is, two-thirds of the wattless current is compensated for.

Or in other words, by using the two impedances Y_3 and Y_5 of the values calculated above, on a single-phase circuit, a three-phase relation of E. M. F.'s is produced, that is, the motor operates as three-phase motor with the same maximum output, torque, etc., but with a lesser current input, that is higher power factor, the wattless component of current being reduced to one-third. That is in the two sides of the E. M. F. triangle produced by the capacity inductance device, the total magnetizing current is supplied by the capacity, and the supply current gives the magnetizing current of one-phase only.

Obviously to maintain three-phase relation of E. M. F.'s, the susceptances b_3 and b_5 have to be changed with the speed as the above given functions of b and g.

Thus from the values of power factor and current and E. M. F., calculated for the motor as three-phase motor, the total admittance of the motor:

$$Y = \frac{\mathbf{I}_0}{\mathbf{E}_0} = \frac{(b_1\,c_1 + b_2\,c_2) + j\,(b_2\,c_1 - b_1\,c_2)}{c_1^2 + c_2^2}$$

is calculated as function of slip s, and herefrom the impedances Y_3 and Y_5 as functions of the slip s required to give a three-phase triangle and the current input of the motor calculated:

The load curves of the single-phase motor with two impedances Y_3 and Y_5 adjusted so as to give a three-phase triangle are shown in Fig. 14, the speed curves in Fig. 2 and 15, and the volt-ampere input as function of the torque, reduced to the same maximum torque of 1500 synchronous watts as the other motors, that is, to 77.5 volts at the terminals, is given in Fig. 9.

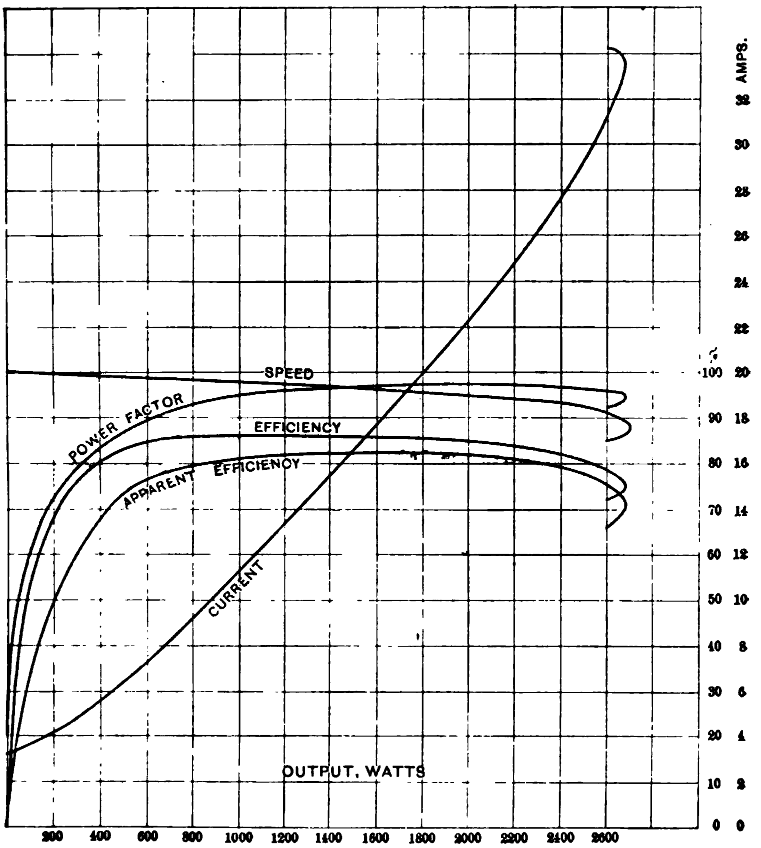


FIG. 14. Load Curves of Single-Phase Motor with Condensance-Inductance Device.

$e_0 = 110$

In this case, where exact three-phase relation is produced, the motor can be calculated as three-phase motor, with the only exception of the current input I_0, which is given by above formula, and the quantities dependent thereupon as Q_0, P_0, etc.

Where no three-phase relation is produced, but for instance fixed amounts of capacity and of inductance inserted, the calculation is the same as in the chapter on the single-phase motor with condenser in the tertiary circuit, except that the motor now contains two tertiary circuits, one closed by capacity admittance Y_4 and one by inductive admittance Y_5, and thus in determining the secondary current two tertiary currents $e\,[1 - (1 - s)\,h_3]\,Y_4$ and $e\,[1 - (1 - s)\,h_5]\,Y_6$ have to be considered.

As seen, with three-phase relation of E. M. F.'s the load and speed curves of the motor are those of the motor as three-phase

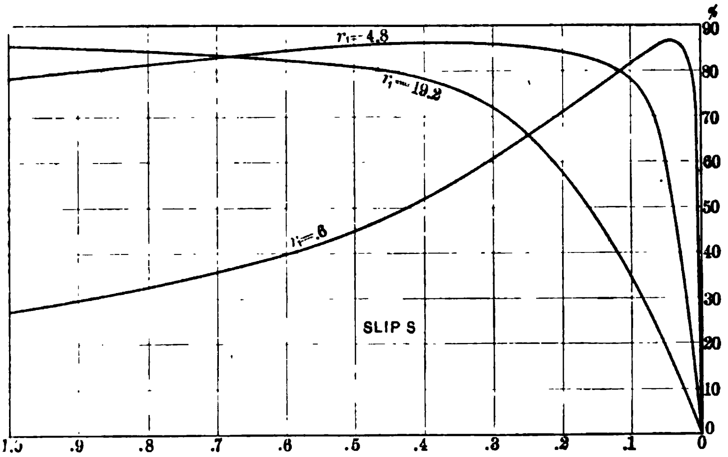


FIG. 15. Speed Curves of Single-Phase Motor with Condensance-Inductance Device. Apparent Torque Efficiency.

motor, except that the efficiency is slightly lower due to the energy loss in condenser and inductance, and the power factor greatly raised, from a maximum of 79% to a maximum of 97%, or almost unity. As a result, the apparent efficiency and the apparent torque efficiency are far higher than those of the three-phase motor and higher still than those of the single-phase condenser motor at constant capacity in the tertiary circuit. Or in other words, this motor requires the lowest volt-ampere input of all, for a given torque.

The impedance Y_3 is always a capacity. The impedance Y_5 is with short-circuited low resistance armature as shown in Fig.

15, a capacity from standstill up to a certain speed, then becomes an inductance, and very close to synchronism again a capacity. With high resistance armature or rheostatic control it is always an inductance, except very close to synchronism.

It thus follows, that in single-phase induction motors with a condenser in the tertiary circuit, compensating or slightly over-compensating for the exciting current at load, an apparent torque efficiency or torque per volt-ampere input can be produced equal or higher than that of the same motor on polyphase circuits, and with rheostatic control of the secondary, a starting torque per volt-ampere fully equal to that of the motor under the same conditions on polyphase circuit. The maximum starting torque, however, which can be produced thereby is limited, and thus, where a very large starting torque is needed, in addition to the capacity, an inductance in the third phase of the motor is required. Hereby, by producing an equilateral E. M. F. triangle in starting, in the single-phase motor, the same starting torque can be produced as given by this motor on three-phase circuit, that is, a starting torque far exceeding the maximum torque of the motor when running single-phase or with condenser in the tertiary circuit.

In the preceding I have discussed the theoretical side of the problem only, but may remark that practical experience during the last few years has fully proved all the conclusions deduced.

Schenectady, N. Y.
January, 1900.

DISCUSSION:

DR. PUPIN :—I would like to ask Mr. Steinmetz to make a picture of how the armature stood and the secondary circuit and the tertiary circuit and the condenser. I cannot make out from the paper what the exact arrangement was.

MR. STEINMETZ :—The primary or impressed circuit is mounted on the stationary member of the motor. The secondary circuits are distributed over the rotating member in polyphase winding. The tertiary circuit is arranged on the stationary member of the motor, thus in constant relative position to the primary circuit, theoretically at 90° angular displacement. Applied to the three-phase wound motor with star or ring connected stationary winding, of terminals, 1, 2, 3, terminals 1 and 2 are connected to the primary impressed E. M. F., terminals 1 and 3 to the condenser as tertiary circuit, and referring to the last chapter of the paper, the inductance used as second tertiary circuit is connected to terminals 3 and 1.

DR. PUPIN :—It seems to me that there is a reaction there between the circuits. Take the first case where Mr. Steinmetz put the two circuits first at right angles to each other and puts a condenser in one of the circuits. Well, the two will still react upon each other through the secondary. Now it does not make any difference whether that condenser circuit reacts upon the primary directly or indirectly, the reaction will be there. It is as far as I can see through it—of course I do not pretend to be able to analyze completely the whole arrangement at a moment's notice,—I have not seen the paper before—but I think it is just the same case as that investigated by myself in 1895, the effect of a secondary circuit on a primary when the secondary contains a condenser in it, which I at that time called *consonance*, and which was investigated by Mr. Steinmetz afterwards, and by Feldman in Germany. It is simply this: You can influence the phase of a primary circuit by a condenser in the circuit itself, which is not always an advisable thing to do because that circuit may have a very large self-induction and very high voltage, and if you put a condenser in there, either in series with that self-induction or in parallel, you will have trouble. You will have very large rise of potential and probably a breaking down of the condenser. So at that time I suggested that it would be advisable to use a secondary circuit with a small self-induction, and large capacity. You could get that way a large current, therefore a large magnetomotive reaction, and therefore a powerful regulation of the phase of the primary current. So that looking upon those matters in this way, I should be inclined, I suppose, partly for selfish reasons, to think that Mr. Steinmetz's arrangement is a particular case of electric consonance. I do not mean to claim an anticipation of the ideas contained in this paper. But I mean to say that, analyzing Mr. Steinmetz's arrangements to its last scientific principles, I would say they are about the same thing as electrical consonance. I do not, of course, wish to say anything that might in the least diminish the credit for the work which Mr. Steinmetz describes in his able paper. In dealings with circuits like that, if you employ condensers you feel just like a baby walking on a slippery floor. The work is exceedingly delicate and laborious and sometimes interesting, sometimes very tedious. It requires a large amount of work before you get things right. It seems to me that Mr. Steinmetz has experienced that, because in his paper he seems to use coaxing terms. Where we say "reactance" of the circuit and "impedance" of the circuit, he uses coaxing terms as "admittance" and "permittance," as if to say: Just come in, dear current, don't be afraid, and he seems to get the current to come in and do the work he wanted it to do.

MR. CHAS. S. BRADLEY:—In 1895 I did considerable work on this line of motors and it was partially suggested by Dr. Pupin's work on consonance. There are several ways of arranging these circuits and I have always believed that one of the best was to have one circuit at one angle and another one at a slight angle say, at an angle of about 60 degrees, with the inductance in it. Imagine that this is the secondary (referring to sketch) wound for three-phase, with a three-phase condenser, a slight effort of rotation produced by an angular coil will cause a three-phase current to be set up in the secondary and a rotation of the magnetism, while the armature is standing still, and with the three-phase condenser the conditions are more thoroughly established so that it gives the motor a directive effort at once if the inductance is properly proportioned to the condenser, the condenser will then take off all the lag due to the additional inductance and also the inductance of the motor. The motor is self-starting and is a consonance motor, its secondary circuit being in a consonance relation with the primary and by increasing and decreasing its capacity the motor can be made to give full torque from start to complete load.

MR. STEINMETZ:—There is one essential difference between the arrangement discussed by me and the application of the condenser in a transformer secondary called by Dr. Pupin, "consonance," or Mr. Bradley's condenser motor, and that difference is that the condenser in my arrangement is not in a secondary circuit to the primary impressed circuit.

Thus, taking the theoretically simplest case of a tertiary circuit in stationary quadrature position to the primary circuit, with a single-phase E. M. F. impressed upon the primary circuit and the motor at standstill, a voltmeter in the condenser circuit shows no voltage at all, that is the condenser is neither in consonance relation nor in any other way induced by the primary circuit. Only when the motor begins to rotate, voltage and current appear in the condenser circuit, increasing with the speed, and induced by the secondary currents flowing in the short-circuited revolving armature, which as I have explained, are carried by the rotation more or less into quadrature position to the impressed circuit, and thus into inductive relation to the tertiary or condenser circuit.

This difference is very important and essential, since it makes the operation of the condenser independent of the wave shape of the primary E. M. F. Whatever may be the wave shape of primary impressed E. M. F., the magnetic flux interlinked with the secondary circuit is absolutely constant and uniformly rotating, since it passes the short-circuited low resistance secondary winding, and since only the secondary magnetic flux can reach and induce the condenser circuit, the E. M. F. induced in the latter is a perfect sine wave irrespective of the wave of primary impressed E. M. F.

The term "admittance" is nothing new, but was introduced by me years ago in denoting the reciprocal of "impedance."

With regard to the liability of excessive rise of voltage and the need of carefully adjusting the condenser capacity, this does not exist with the condenser in the tertiary circuit of the induction motor.

While the general rule is to use a volt-ampere capacity of condenser equal to the volt-ampere input of the motor running light, no need exists of being so particular about the amount of condenser, but no harm results if you put 50% more or less condenser in circuit. With the right amount of condenser we get 100% power factor. By using 50% more we perhaps get 95% power factor, somewhat more starting torque, and a slightly leading current, and with 50% less condenser perhaps 95% power factor, somewhat less starting torque and slightly lagging current.

Very careful adjustment and excessive rise of voltage are features incident to the use of capacity in series to inductance. But there is an essential difference between capacity in series and capacity in shunt, as pointed out some years ago by Mr. Wm. Stanley and me.

Capacity produces leading currents. Thus, if you connect a capacity in shunt to a circuit with lagging current, as an induction motor, whether directly or through transformer, the lagging current is reduced by as many volt-amperes as the condenser gives leading current, but no rise of voltage occurs.

If the volt-amperes condenser are equal to the lagging volt-amperes of the circuit, the latter will be entirely compensated and disappear; if less condenser is used, some lagging current remains; if more condenser, some leading current remains after neutralizing the lagging current.

This feature I use in the induction motor. The lagging component of induction motor current is neutralized by the leading current of the condenser in the tertiary circuit, and thus disappears more or less completely. As easily seen, no great accuracy of adjustment is needed, but 20% condenser more or less does not change the power-factor noticeably from unity.

Different it is with the use of the condenser in series to an inductance. By inserting a capacity reactance equal to inductive reactance in series, the E. M. F. of self-induction is balanced against that of the capacity and the total impressed E. M. F. re-

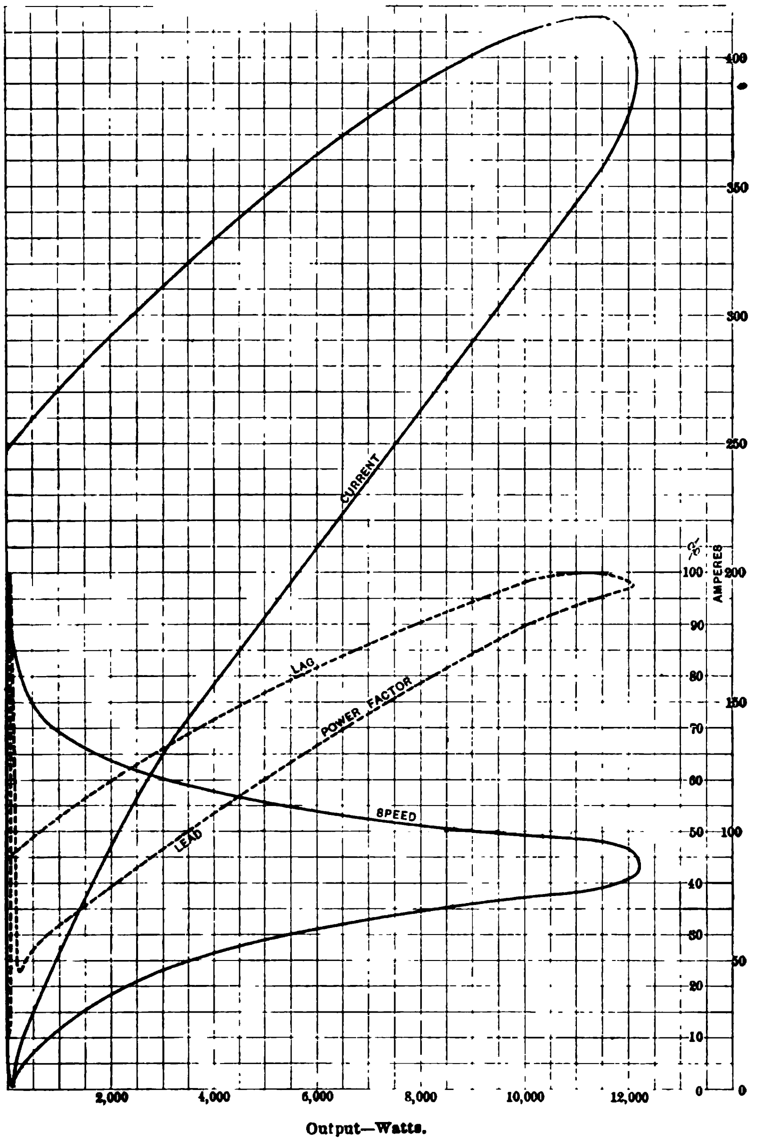


FIG. 16. Induction Motor. Load curves. Capacity Reactance in Secondary.

$$k_1 = .2$$

$$Z = .1 - .8j \quad Y = .01 + .1j.$$

mains available for sending current through the resistance of the circuit. Thus the current rises excessively, and correspondingly the voltage, but capacity and inductance have to be adjusted to equal reactance, with great accuracy. This is the arrangement where capacity causes excessive voltages and great accuracy of adjustment is required. But it has nothing whatever to do with the use of capacity to compensate for lagging currents.

Regarding Mr. Bradley's experiments on using three-phase condensers in the secondary of an induction motor, I have been very much interested therein and have theoretically investigated it some time ago.

One objection is that its application is limited to a sine wave of impressed E. M. F., since no short-circuited secondary exists, but the condenser in the secondary tends to intensify the higher harmonics.

Another objection is the very large size of condenser required, many times larger than with the use of condenser described by me, especially if you want to run up to near full speed. At one-half speed about twice as much, at three-fourth speed four times as much capacity is required as at standstill, since the frequency impressed upon the condenser is that of slip.

With a given capacity in the secondary circuit, the motor gives a large torque at a certain intermediary speed, depending upon the capacity, but very little torque above and below this speed.

The load curve of such a motor of constants:

$$Z_0 = Z_1 = .1 - .3j$$

$$Y_0 = .01 + .1j,$$

and capacity reactance:

$$k = .2$$

per secondary circuit, is shown in Fig. 16; the speed curve for the two values of capacity reactance:

$$k = .2 \text{ and } k = 1.0$$

in Fig. 17, while Fig. 18 gives the speed curve of the motor for constant torque $T = 4800$ synchronous watts, and variable capacity reactance.

This is the same motor of which the curves as three-phase motor and as single phase motor under the different conditions of operation and of starting, are shown in my two previous papers of 1897 and 1898.

MR. BRADLEY:—I have a large volume of actual work, observations from motors of this kind, and with the permission of the INSTITUTE I will read a paper on this subject at a future time.

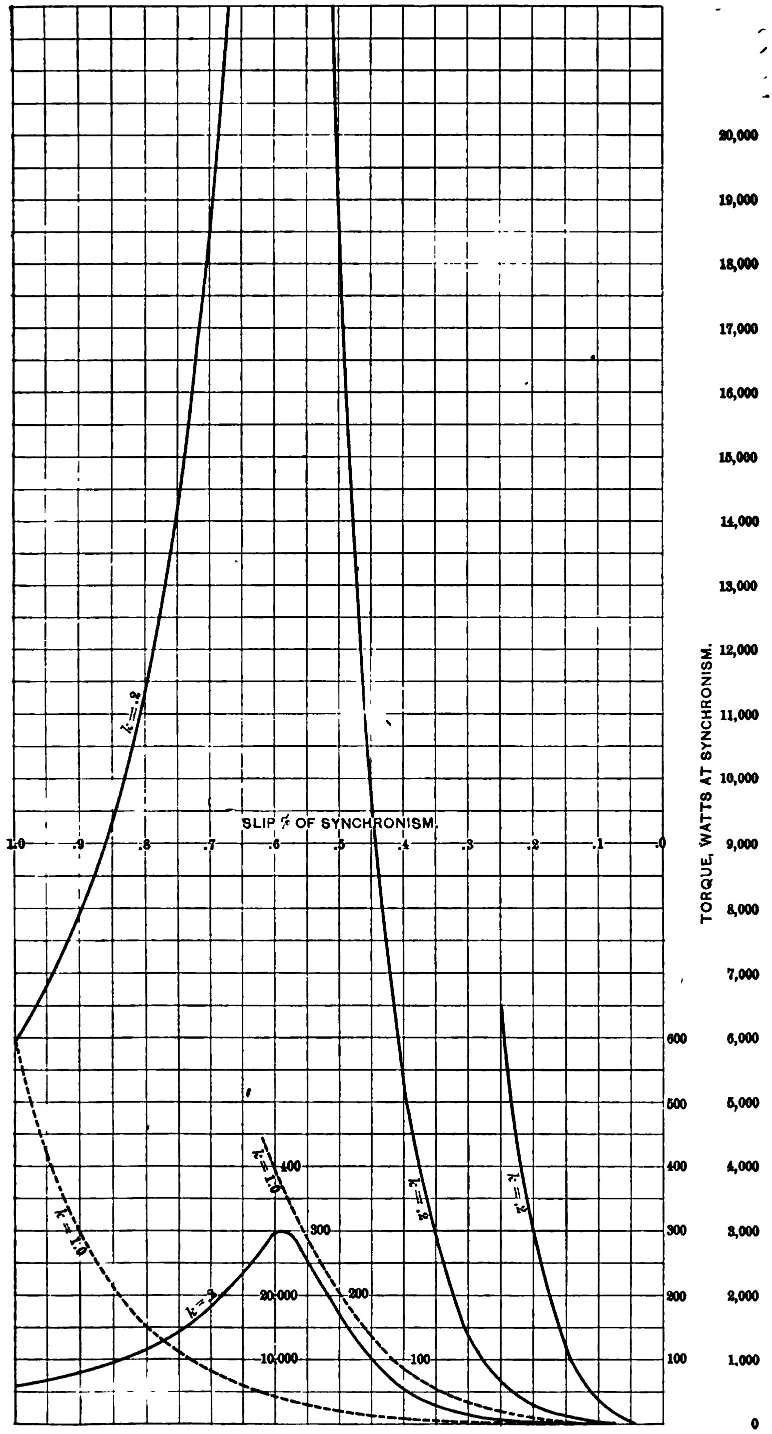


FIG. 17. Induction Motor. Speed Curves. Capacity Reactance in Secondary.

$k = 1.0$ and $k = .2$.

$Z = .1 - .8j \quad Y = .01 + 1j$.

Mr. Steinmetz:—I think that would be extremely interesting for the **Transactions**. I have investigated this matter theoretically, but there is no experimental work published in that line and undoubtedly the results would be of interest.

Dr. Pupin:—There is one question which I would like to ask Mr. Steinmetz, and that is, I do not quite understand why he considers the effect of that short-circuited secondary on account of its killing upper harmonics as so important, because as a rule the impressed electromotive force of the ordinary alternators, such as are made by the General Electric and the Westinghouse Company, when they are not simple harmonics, have complex harmonics which are comparatively speaking, weak in comparison to the fundamental. I do not know of a case that is a very serious exception to that rule. Well, the

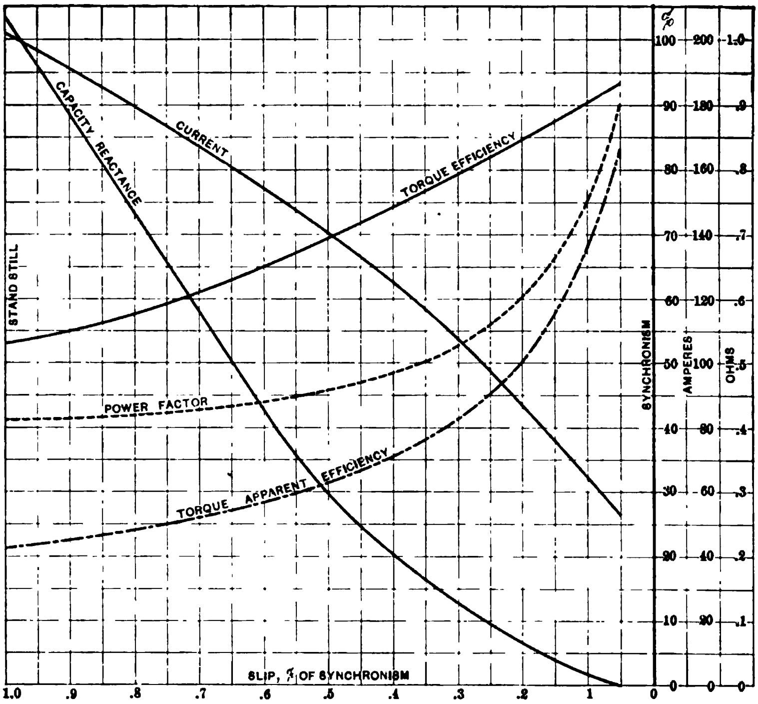


Fig. 18. Induction Motor.

$Z = .1 - .8j \quad Y = .01 + .1j.$

Starting with Constant Torque

$T = 4800$

And Variable Capacity Reactance in Secondary.

fundamental will do the principal work if you allow it to do so. Now if you use a tertiary circuit, or a secondary circuit for that matter, with a condenser in it and you give that condenser the proper capacity to assist the fundamental of the primary, that is all which you need do. Who cares what the other harmonics will do? Because they are not so very important anyhow, and you are simply working as if the upper harmonics were not present at all. Everybody knows that you can treat all these independent components entirely independently; treat each one by itself as if the others were not present. So that even if the upper harmonics are there, in the tertiary circuit, provided the capacity is such as to assist the fundamental and not assist the upper harmonics, I think the circuit will work just as well. The capacity introduced there will not help the upper harmonics to develop an undesirable current there. It will simply assist the fundamental. Of course, I would like Mr. Steinmetz to point out more particularly the importance of watching the upper harmonics, but I do not really see the importance of it.

MR. STEINMETZ:—It is true the motor will run just as well with the higher harmonics present. It will run also without condenser if once started. But without condenser it runs with poor power factor due to excessive lagging currents, and the main object of the condenser is to compensate for these lagging currents.

As I have shown, however, in the paper, it does not take much distortion of wave shape to produce so much current of higher frequency in a shunted condenser, that in spite of the elimination of the fundamental wave of lagging current the total current actually increases, that is the power factor drops by the insertion of the shunted capacity. We must consider that the current in a condenser is proportional to voltage and to frequency, thus for instance a seventh harmonic in the E. M. F. wave of only 10% of the fundamental, produces in the condenser a seventh harmonic of current of 7 × 10. or 70% of the fundamental.

As a rule, due to the self-inductive reactance of the transformer or compensator feeding the condenser, which is also proportional to the frequency, the higher harmonics of current are still further increased. Thus, for instance, it is nothing unusual when connecting a condenser across an alternating circuit to find that it takes two or three times as much current as calculated from capacity, frequency and voltage, and to measure the capacity of a condenser from volt and ampere readings, it is necessary to insert in series to the condenser a very high resistance or inductance to eliminate the effect of the higher harmonics.

I am somewhat inclined to suspect that the distortion of the current wave which Dr. Pupin observed in his condenser tests and attributed to a kind of dielectric hysteresis, was nothing but the higher harmonics of current produced by the higher harmonics of the impressed E. M. F., the latter being too small to be directly observed, while when multiplied in the condenser they were noticed.

DR. PUPIN:—That is the first thing a man ought to think of when he gets distorted current, whether that is not due to the presence of upper harmonics in the impressed electromotive force. To overlook that, of course, would be a very serious error on the part of a man who knows anything about experimental work. In the first place I analyzed that alternator a year and a half or two years before that, in 1894, and I knew exactly that the fundamental was very, very much larger than the upper harmonics. In fact of the upper harmonics there was only one that amounted to anything at all and that was the third harmonic which was a very small percentage of the fundamental. I have forgotten now, but it was something like one or two per cent. Now if this current were due to the presence of the upper harmonics, the shape of the current curve would not depend upon the voltage at all. It would remain just the same no matter whether you have a small voltage or a large voltage. Well now, as a matter of fact, the shape of the current depended very much on the voltage. It shows that as we increase the voltage, of course, the leakage and the specific inductive capacity will increase, and, of course, the deviation of the current from the simple harmonic form will increase much.

The next point is this: Mr. Steinmetz says that if you introduce a condenser in the presence of the upper harmonics you get very large condenser currents, that is so large that the condenser current in the fifth harmonic is just as large as that of the fundamental. That I do not admit for one moment. I think if you arrange your condenser properly, say that the fundamental of the impressed electromotive force is six times as large as the fifth harmonic if you would arrange your condenser properly, the fundamental current ought to be not only six times as large but at least thirty times as large as the fifth harmonic—at least that. The arrangement is ineffective if you do not get as much effect as that.

MR. BRADLEY:—It all depends upon the adjustment of the condenser and inductance. If they are adjusted for fundamental, even the third harmonic is choked-out, especially if it is in the secondary. In order for these motors to work well, the adjustment should be very nicely made; that is the condenser and inductance should be adjustable for what Dr. Pupin calls consonance if it is in the secondary; if it is in the primary it ought to be for resonance. If it is in resonance for the fundamental the current is almost entirely choked out for the third or fifth or any other harmonic. Only the fundamental is augmented. The others are dampened.

MR. STEINMETZ:—In the last discussion Dr. Pupin and Mr. Bradley have been speaking of something entirely different from what I am using. I referred to capacity in shunt to the lagging circuit, while their remarks apply only to capacity in series to inductance with its inherent defects of excessive voltage rise and excessive care of adjustment.

Series capacity was tried by Mr. Wm. Stanley some years ago, but given up as commercially impracticable, since the unavoidable variations of frequency in commercial circuits are so large as to throw the adjustment between capacity and inductance out of balance. Thus any attempt at using series capacity must be doomed to failure, except when used as by Mr. Bradley in a movable secondary circuit, which adjusts its frequency to that of balance between capacity and inductance.

With shunted capacity as the only way in which capacity can be used practically, there is no adjustment for this or that harmonic, but each harmonic takes current in proportion to its E. M. F. and frequency.

Regarding Dr. Pupin's remark that the generator for such induction motor should not give any higher harmonics, we must consider that in single phase circuits, mostly small and medium size systems of 125 cycles, the motor load is an incidental feature only, which while quite desirable is not of sufficient importance to warrant the installation of a type of generator which increases the continuous loss of energy in the transformer cores by something like 10%. Still less can it be expected to throw out the existing generators and install new ones to accommodate a few induction motors. Thus, the problem of the single-phase induction motor is to build them so as to run satisfactorily, with higher power factor and fair efficiency, on such E. M. F. waves as given by the existing single-phase systems.

Regarding Dr. Pupin's observation that the shape of the current wave impressed upon a condenser changes with the impressed voltage, this rather tends to point to my explanation, of these higher harmonics of current being due to higher harmonics of the impressed E. M. F, since when changing the voltage by changing the excitation of an alternating current generator, usually the shape of the E. M. F. wave, that is the relative values of its harmonics vary more or less.

DR. PUPIN:—These harmonics were studied with very great accuracy. I used the resonance methods of analysis. We could detect as much as the fifteenth harmonic by the use of the telephone. But with an accurate voltmeter we could not detect anything beyond the third, all the others were too small. About that adjustment for the fundamental and the upper harmonics, Mr. Steinmetz says that if you use a condenser in the secondary circuit that you do not get these rises of current so much, that simply all you have to do is to compensate for phase. To be sure that is very true. You do not get a rise in the primary current. The primary current is only affected with regard to its phase. But the circuit which contains the condenser, that current increases very much, and if you adjust your capacity there so as to produce a very large effect upon the phase of the primary current, then the current in the tertiary or secondary circuit containing the condenser will be very large. That is my point. It must be so. How otherwise could a few turns in the secondary circuit with a condenser in it produce a large effect on the phase of the primary unless you had a very large current in that secondary. That phase effect is only produced by the counter-magneto force being produced there. If you want to produce there a sufficiently strong counter-magneto force with a few turns you must necessarily have a large current.

Mr. Steinmetz:—The object of the condenser in the induction motor is to produce a minimum current input, that is approximately 100% power factor, by compensating for the wattless magnetizing current of the motor. In this case the amount of capacity required is moderate and the current in the condenser circuit is correspondingly small. There is indeed a second value of capacity giving 100% power factor with maximum current input, in balancing the internal self-induction of the motor.

In this case an excessive rise of voltage occurs. This case takes some 10 to 20 times as much capacity as used, and causes currents to flow far beyond the heating limit of the motor, and thus is of no practical importance.

Dr. Pupin:—I have investigated that point. I call that the second critical point. That is not the point at which you work. You work at a point where you know the current will remain small in the primary circuit.

Mr. Steinmetz:—The actual condition of the motor corresponds to what Dr. Pupin calls the "first point of consonance," but as I pointed out when Dr. Pupin published his investigation some years ago, the introduction of the term consonance for both critical points is very unfortunate, since it combines entirely different phenomena in one name and thus leads to misunderstanding and confusion, as to-day's discussion has shown again.

[Adjourned.]

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, February 28th, 1900.

The 140th meeting of the Institute was held this date at No. 12 West 31st Street and was called to order by President Kennelly, at 8.15 P. M.

The Secretary announced the election at the meeting of the Executive Committee in the afternoon of the following associate members:

Barnes, Howell Henry	General Engineer, Mexican Electric Works Ltd. Apartado, 905 Mexico City.	C. F. Beames. H. S. Wilson. J. W. Thompson.
Boyd, John Duncan	Electrician, Yuba Electric Power Co., Marysville, Cala.	F. V. T. Lee. T. E. Theberath. F. A. C. Perrine.
Evans, Clement W.	Electrical Engineer, American Engineering Co., Box 2100 Mexico City.	C. F. Beames. J. W. Thompson. H. S. Wilson.
Henry, Lewis Warner	Assistant in Engineering Department, Mexican General Electric Co., Mexico City.	C. F. Beames. A. E. Worswick. H. S. Wilson.
Hunt, A. M.	Consulting Engineer, 331 Pine Street, San Francisco, Cala.	Clarence L. Cory. R. S. Masson. Wynn Meredith.
Lawrence, Wm. G.	Manager of Light and Power Department, Town of Hudson, Hudson, Mass,	C. B. Burleigh. Geo. P. Low. Wynn Meredith.
McCreary, J. L.	Constructing Engineer, District Railway Co., Mexico City.	A. E. Worswick. C. F. Beames. J. W. Thompson.
McVay, H. D.	City Electrician, City of Wichita, Wichita, Kansas.	Samuel Sheldon. Herbert L. Webb. C. O. Mailloux.
Neurath, Morris M.	Consulting Engineer, 1444 Monadnock Block, Chicago, Ill.	Geo M. Mayer. S. G. Neiler. R. H. Pierce.

Renstrom, Frans Oscar	Superintendent, The Regla Power Co., Apartado 95, Pachuca, Mexico.	C. F. Beames. J. W. Thompson. H. S. Wilson.
Schiaffino, Mariano L.	Chief Electrician, Compania de Luz Electrico, Guadalajara, Mexico.	C. F. Beames. J. W. Thompson. H. S. Wilson.
Smith, Walter Eugene	Electrician, The United Electric Improvement Co., 19th and Allegheny Ave.; residence, 2010 Ontario Street, Philadelphia, Pa.	R. H. Klauder. Herbert Lloyd. J. B. Entz.
Wiley, Geo. Lourie	Manager, Standard Underground Cable Co., 18 Cortlandt St., New York; residence, Arlington, N. J.	John J. Carty. Ralph W. Pope. T. D. Lockwood.
Zapata, J. M.	Constructing Engineer, The Mexican General Electric Co., Apartado 403, Mexico City.	C. F. Beames. J. W. Thompson. H. S. Wilson.

Total, 14.

Transferred from associate to full membership.

Approved by Board of Examiners, January 12th, 1900.

Edward J. Willis Steam and Electrical Engineer, Richmond, Va.

Dr. Pupin read the following note.

A note presented at the 140th Meeting of the American Institute of Electrical Engineers, New York, February 28th, 1900. President Kennelly in the Chair.

A FARADMETER.

BY M. I. PUPIN.

The art of measuring the capacity of a condenser has not yet reached that stage of perfection which can be justly claimed for the resistance measurement. The prevailing method is the ballistic galvanometer method. Leakage and absorption can and often do introduce serious errors into this method. These errors can be reduced to any desirable limit by employing alternating currents of appropriate frequency.

This was the principal consideration which led to the construction of the faradmeter which forms the subject of this note. In addition to this consideration, which concerns the accuracy, there is another very important consideration which must be taken into account and that is the convenience of the method and the cheapness and durability of the apparatus to be employed. Much of the capacity measurement work, especially in connection with telegraphy, telephony, and the construction of alternating current machinery, has to be done under conditions under which it is quite inconvenient to employ the ballistic galvanometer. I believe that the faradmeter described here will be found to answer quite satisfactorily all reasonable requirements as regards convenience.

The theory on which the construction of this meter is based is very simple, as follows: Let $x\ y$ (Fig. 1) be a conductor through which an alternating current flows. D is a condenser of known capacity and E is a condenser of unknown capacity; F is a differentially wound telephone. Connect as indicated and adjust the resistances A B and B C until silence is obtained in the telephone. Then capacity of D : capacity of E :: resistance of B C : resistance of A B. It is understood, of course, that the

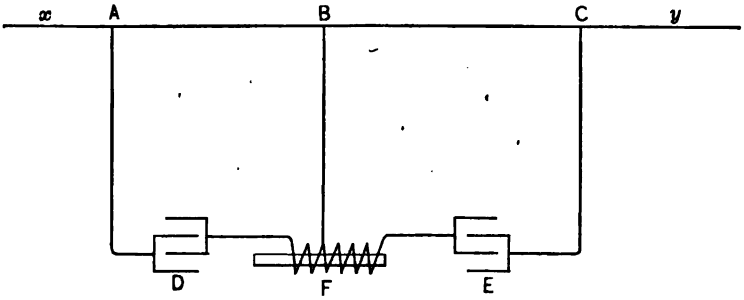


Fig. 1.

resistances A B and B C are non-self-inductive and that the capacity reactance of each condenser is in its own circuit by far the greatest element of the impedance. It will be seen presently that these conditions are fulfilled in the apparatus shown in Fig. 2 which our fellow member, the well-known mechanician, Mr. Baillard, constructed for me and employed in some work which he has been doing for me during the last two months.

In Fig. 2, A is a cell which feeds into the primary B of a small induction coil provided with an interrupter such as is used in

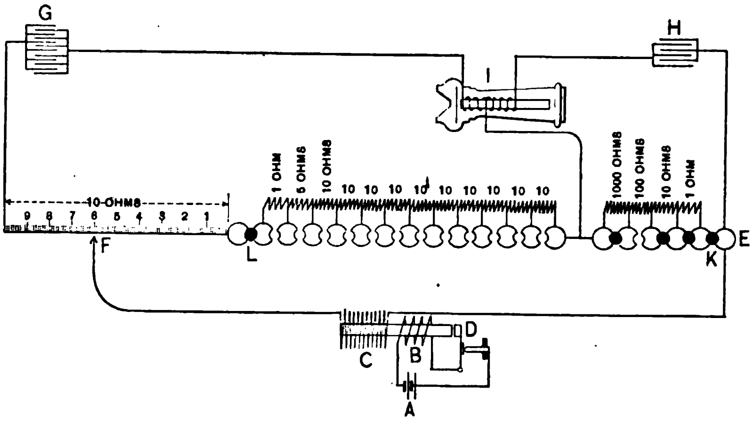


Fig 2.

electrotherapy. The secondary C is connected to a row of resistance coils E and L. These resistances are arranged in convenient steps as indicated. The resistance coils L have in addition several equal lengths of manganin wire F stretched over a graduated scale. The resistance of the coils as well as of the manganin wire is carefully calibrated once for all. The condenser H is a carefully constructed mica condenser of known capacity. G is the condenser the capacity of which is to be determined. I is the differentially wound telephone. The approximate adjustment is accomplished by the plugs which control the resistances E and L, and the final adjustment is made by the manganin wire by a sliding contact F which varies the length of the manganin wire to be introduced, and therefore varies the drop which acts on one of the condensers. With ordinary frequencies, capacities up to several microfarads can be determined with an accuracy of a small fraction of one per cent. easily and rapidly.

It is self-evident, of course, that in place of the differentially wound telephone I, we can use an ordinary telephone and place it in the bridge which connects a point between G and H to a point between the resistance coils E and L. The conditions of balance are the same as in the method employing the differentially wound telephone. In many practical cases this second method is preferable.

Mr. Baillard has experimented quite a great deal with a faradmeter of this kind and is better prepared to go into details of the apparatus and the method than I am.

DISCUSSION.

THE PRESIDENT:—The apparatus which is before you represents a means for measuring capacity as a shop instrument, or as a swiftly measuring engineering instrument, contrasted with the older method of galvanometer work, and introduces the peculiar idea that the capacity of a condenser, as measured in accordance with its commercial use in alternating current phenomena, may be somewhat different from its capacity as measured according to the ordinary definition and in the ordinary way. In other words the capacity, as defined by the charge per unit of pressure applied at the terminals, is not exactly the same in every practical case, as the capacity of a condenser determined by its impedance to the flow of alternating current, and in this case the impedance method is represented, which is very swift, and no doubt supplies a very great want in workshop practice. Of course the same plan of measuring capacity by means of alternating currents is not entirely new, but the apparatus which is before us possesses very interesting features.

MR. CARL HERING:—I would like to ask Dr. Pupin whether the result obtained by such a measurement of a capacity would be likely to be different from that obtained by the usual method, and if so about how much might it differ.

DR. PUPIN:—I know that there is a difference, and I never had much confidence in capacity measurements of paraffin condensers. With the ballistic galvanometer method the differences will depend, of course, on the experimenter. It may be large, or it may be small, depending on what precautions you take. The other day Mr. Baillard and myself took a condenser made by a manufacturer whose name I do not care to mention. It was sold for a one-half microfarad standard; we used it as such. Mr. Baillard made a lot of condensers for me and measured their capacity in terms of this standard. We began to suspect the standard, and I put in a slight protest against it. Then we determined it in terms of another standard by the method described this evening, and found it forty per cent. off. But if its capacity was determined by the ballistic galvanometer, it could be made to read all right. Now the reason for that was, we found afterwards, that it had too much leakage. The insulation resistance was only 250,000 ohms. Well, of course if we have an insulation such as that, and determine the capacity by the ballistic galvanometer method, we may get anything for capacity. I know it as a matter of fact that paraffin condensers may have considerably smaller capacity when determined by alternating currents than the capacity obtained by the ballistic galvanometer; but I am not prepared to say exactly how much. But I certainly am prepared to say that in many cases it is more than good engineering practice ought to permit. If the paraffin condenser is made in the most careful way, under a vacuum, heated, and so forth, so that it contains no air and no moisture, and other imperfections, then it would be all right. But if a paraffin condenser is made in the old-fashioned way, without any modern precautions being taken while being manufactured, then the difference can be certainly over five per cent., and that is more than good engineering practice ought to permit. I do not think that these precautions have to be observed as rigidly in the manufacture of mica condensers, or condensers made of hard rubber, where the insulation is very high, and the specific inductive capacity does not vary much with voltage; but in paraffin paper it makes quite a difference.

Dr Louis Duncan:—May I ask whether the question of capacity—ten per cent.—is not a question between absorption and the treatment of condensers. You may make a paraffin condenser, and the question about what its capacity is, is a question of absorption largely, also of manufacture of the condenser. It might vary not only five per cent. but 25.

Dr. Pupin:—It may be anything at all, where there is much leakage current.

Dr. Duncan:—So that capacity is not so important as the history of the condenser?

Dr. Pupin:—The history of the condenser exactly. It may be anything. You cannot tell what it is going to be, voltage leakage, etc., have to be taken into consideration.

Mr. Townsend Wolcott:—I would like to ask if this current used was simply an interrupted current.

Dr. Pupin:—An alternating secondary, produced by an interrupted primary current. Where there is an alternating current it would be very much better to dispense with the buzzer of the faradmeter and use the alternating current. The other day I was down at the New York Telephone Building, and I inquired about the capacity of the cables, in which something like vulcanized rubber was used for insulation, and I was told it was so and so much per mile. I said: Are you sure about that? They said: We are not sure at all. We determined it by ballistic galvanometer, and we do not know how near we are to the true capacity. Although methods of the class to which the method described this evening belongs are not, I suppose, altogether new—I do not think they are; they are too self-evident to be new—but the fact is that nobody has reduced them to practice.

Mr. Charles S. Bradley:—Do you think that a cable would take its charge quick enough to be treated the same as a condenser?

Dr. Pupin:—Well, the cable should not be allowed to take its charge in the ordinary commercial sense—that is to say, the cable should not be given time enough to soak in its charge.

Mr. Bradley:—But if it is a long cable, it will take some time for the charge to reach the other end.

Dr Pupin:—Oh, yes. You mean the distributed capacity. Thirty periods mean six thousand miles wave length, very roughly. Up to 300 or 400 periods per second there would be no trouble. You could take a cable of 300 or 400 miles length and determine its distributed capacity just as if it were an ordinary condenser.

Mr. Carl Hering:—It seems to me this method is especially applicable for measuring a capacity under the very conditions under which it is to be used in practice, and it therefore has some advantages over the ballistic method. The frequency of telegraph, telephone or power currents are quite different from each other. I should imagine that with this method different results would be obtained with different frequencies, and in measuring the capacities of cables or any other apparatus, the frequency of the current used for the test might be made equal to that with which the apparatus is to be used in practice, as, for instance, those for telegraphic, telephonic or power purposes. The virtual or effective capacity for that particular frequency might therefore be determined more reliably in this way than by the usual ballistic method.

Dr. Pupin:—Different frequencies and different potentials—the capacity of the paraffin condenser depends to some extent on the difference of potential applied to it.

Mr. Hering:—Could you use different voltage in this method?

Dr. Pupin:—Yes, you can.

Mr. Hering:—Provided the resistance will stand it.

Dr. Pupin:—Oh, yes. Well, that is simply a question of spending money to get the prŏper resistances.

Dr. Duncan:—It would not affect anybody here.

Dr. Pupin: The companies interested in capacity measurements have money enough to spend for things of this kind.

Mr. H. D. Reed:—As I understand Dr. Pupin, a ballistic galvanometer has given satisfaction where the insulation was high and steady. Well, you take a cable, any that a telephone company would have, would not be over a mile in length; most of them are much shorter. Now, the resistance of those rubber cables, as a rule, will run from 1,000 to 2,000 megohms per mile. In a short length of cable where your resistance was several times that, I do not see why the ballistic galvanometer would not be all right.

Dr. Pupin:—I did not say insulation alone. Absorption has to do with it, too. You have got to take that into consideration.

The President:—If there is no further discussion of this paper, we will pass to the next, which is entitled "Notes on Electric Traction Under Steam Railway Conditions," by Mr. Edward C. Boynton.

Mr. Boynton read the following paper:

A paper presented at the 140th Meeting of the American Institute of Electrical Engineers, New York, February 28, 1900. President Kennelly in the Chair.

NOTES ON ELECTRIC TRACTION UNDER STEAM RAILWAY CONDITIONS.

BY EDWARD C. BOYNTON.

On many of the large steam railroad systems in the United States, there are certain sections which present the most favorable conditions for the substitution of electricity for steam as a motive power. These conditions are the result of increasing density of population, and mean that better and cheaper transportation facilities are needed by the public than are provided by the steam road.

The electric street railroads quickly took advantage of these conditions, and by building lines more or less parallel to the steam roads, soon acquired a large share of the local passenger traffic. The fault with the steam road was not that the motive power was steam, but the fare was too high and the train service too infrequent. The whole question of the substitution of electricity for steam hinges upon that one point.

In order to provide satisfactory transportation facilities, the steam road must double or quadruple the number of its trains, and reduce the fare to at most one cent per mile. When there is sufficient density of population, this will surely cause a large increase in the number of passengers carried. This increase is due principally to the fact that many people who could seldom afford the expense of traveling would then make frequent trips. It is very doubtful whether the greater number of steam trains can be operated at a sufficient profit with the low fare. Here, then, comes in the change in motive power, with the sole purpose of decreasing the operating expenses.

I wish to call attention to two classes of local passenger traffic which should be considered as distinct from each other. The suburban traffic of a large city is well understood, and its characteristics are usually such as would make the change from steam to electricity profitable. The low fare will induce a part of the population to make their homes in the suburbs, and thus increase the travel. But where there are competing trolley lines, the steam road, which we will suppose has electric motive power, needs one more facility than those mentioned, and that is, high speed. Without that, there would be little advantage over the competing lines.

It has been proved by experience that the speed must be at least as great as an average steam train, and there is no doubt that if the speed be made as high as the fastest steam express train, the popularity of the line would increase. It is well-known that the business man who desires to travel from one city to another, or to and from his residence and his place of business, cannot be carried there too rapidly. It would probably surprise the average passenger on one of the fast steam express trains to be told at a certain time that he was traveling 70 miles per hour, and yet such speeds are reached every day, for short distances, over a straight, level track.

The other class of traffic referred to is that existing between cities and towns in close proximity. Let us assume a case as an example.

In a certain densely populated manufacturing state, there is a city larger than any other within fifty miles radius. Within that radius are several towns and small cities not over twenty to thirty miles from the larger city. These are connected by the steam road, which maintains what is considered a reasonable train service, and one that is as frequent as the traffic seems to demand, at the rate of fare charged, which is from two to two and one-half cents per mile. The trains are quite heavy, nearly always fully loaded, and are run from two to three hours apart. Together with its freight traffic, such a road pays well, judged from the steam road's standpoint. Suppose that electricity be substituted for steam in that section, and a train service consisting of two, or three car trains running every half hour from each end, with a maximum speed of fifty to sixty miles per hour, and the fare reduced to one cent per mile. There is no doubt in the minds of those who have watched the development of such cases, that the increase in traffic and low operating expenses would result in a far greater profit than was ever earned by that section of the road. It is well-known that such conditions exist on our steam railroads in many localities.

It has been said that the steam roads will begin by equipping their branch lines with electric motive power, and little or nothing is heard of the equipment of the main trunk line. It is necessary to define what is meant by a branch. In a large system some branches are 100 miles long and may be double tracked; others are from six to forty or fifty miles in length. In the assumed case described above, the conditions may exist on one of the large branches or even on the main trunk line, which may have four tracks. It should make no difference in deciding the question of equipping the part of the system which possesses the desired conditions, whether it is on a branch or a part of the main line. It should be fully understood that no steam railroad will equip any portion of its lines, except with the provision that nothing shall be done which will prevent the running of steam and electric trains over the same track.

A well known authority, nearly five years ago, mentioned the possibility of the equipment of one or two of the tracks of a four-track trunk line by electricity, to carry the local traffic, and stated that the two tracks equipped should be those used by the freight trains. At the present day that does not seem advisable, for the reason that the speed of the electric trains must be equal to that of the steam express trains, and the slow moving freight trains would seriously interfere with the electric schedule. But it is unlikely that any steam road will equip a part of its main trunk line until it has satisfied itself, as to financial results, by giving it a thorough trial elsewhere.

The reduction of fares combined with the use of open cars during the hot summer months, produce a class of passengers which formerly used the electric street cars. These have been called the pleasure riders, and they furnish a considerable proportion of the receipts. Experience with open car trains has shown that speeds of 30 to 35 miles per hour are the maximum which should be used, on account of the discomfort caused by the wind pressure created by the train.

THE QUESTION OF EQUIPMENT.

The questions, how much will it cost to equip a given service to be operated by electricity?—and how much will it cost to operate it? are frequently asked. The electrical engineer is now in a position to answer both these questions with great accuracy. The experimental stage has passed, and sufficient data is at hand to give all the information needed. It must be realized that the operation of a steam railway by electric power introduces many conditions which do not exist in the transportation problem within a great city, such as are operated by the elevated or surface street railroads. There are no restrictions on speed or weight of trains. Rapid acceleration is not of so much importance, for the stops are much further apart. The trains must be operated under steam rules absolutely, and the whole equipment must comply with the laws relating to steam railway trains. The railway company contemplating the equipment of a part of its system with electric motive power has the choice of several methods which should be closely studied to determine which is best suited for the service it is proposed to operate.

These methods are:

First: The purchase of electric locomotives of sufficient power and weight to haul its standard passenger coaches.

Second: The equipment of a number of its standard coaches as motor cars.

Third: The purchase or building of a sufficient number of special light passenger coaches, some of which are equipped as motor cars, and the withdrawal of its standard coaches entirely from this service.

Fourth: Shall freight be hauled by electricity or steam?

The use of electric locomotives for the purpose under consideration depends upon several conditions. If the travel is heavy, that is 2,000,000 passengers per year and upward, the service frequent, the speed high, requiring an average train of four cars, and, as may be the case, the same coaches must go much further than the electric service extends, hauled by steam, it is advisable to use the electric locomotives hauling standard coaches. Their principal advantage lies in their ability to perform the work of a steam locomotive in every respect, and this is frequently a strong point in their favor with the railway managers. They are thus able to accommodate themselves to congested traffic which usually occurs on holidays and possibly at certain times every day, by simply increasing the number of coaches hauled as is the practice with steam locomotives. Such locomotives should weigh from 100,000 to 150,000 pounds, should have eight wheels and four motors, so that the total weight is available for traction. They must be provided with sufficient power to haul at least double the average train without over-heating. They must not only be able to perform the work of a steam locomotive in the same service, but should do it at a faster schedule speed. The rapid acceleration of a train hauled by such a locomotive enables it to perform the above duty without any increase in the maximum speed. In switching cars, the ease and rapidity with which the electric motor can be handled is a great advantage.

It is necessary to equip these electric locomotives with the best automatic air brake system that can be obtained, for several reasons. They must operate the existing brake system on the coaches as well as the steam locomotive does. The law requires automatic brakes and a whistle. An independent motor compressor with a large main reservoir is therefore almost imperative.

The cost of repairs on an electric locomotive should be exceedingly low. possibly 10% of that required by a steam locomotive on account of the fewer moving parts and the entire absence of the boiler and its necessary equipment.

The fact that an electric locomotive requires but one set of controlling and air braking apparatus is a distinct advantage over other methods of employing electric motive power. This is evident, not only in the first cost but in the fewer parts to be cared for.

The second method of applying electric motive power to an existing steam railway; the equipment of standard coaches as motor cars, will appeal to all steam railway managers as the cheapest and most convenient way to make the change. This method has strong arguments in its favor.

The motor car carries its own paying load and during the hours of light travel can be run light, without hauling other coaches. A standard coach equipped with two motor trucks and four motors will haul nearly as many coaches as the electric locomotive above mentioned and weighs 100,000 lbs. It will easily handle five coaches making a six car train weighing loaded 450,000 lbs. I believe that the power consumed per passenger carried in a train hauled by an electric locomotive will be less than if all the cars were motor cars, whether run singly or in one train.

Let us see exactly what must be done to a standard coach to equip it as a motor.

In most cases the conditions will be found to be such that three or four car trains with a proper schedule will be sufficient to take care of the maximum traffic. This necessitates only two motors for the coach. These should both be mounted on one truck, and this truck complete with motors will have to be purchased and used to replace one of the standard trucks. The motor truck should be built especially for the purpose, a heavy steel truck, 36 to 40-inch, steel tired wheels, brakes of the type that do not require brake-beams, springs both elliptic, and equalizer of sufficient strength to support the weight of half the car body with maximum load, and this means all standing room occupied. The size and general design of the axle in the motor truck must be carefully considered. The author does not believe that steel axles 5″ minimum diameter between wheels, are safe. It may be that in calculating their strength and considering the enormous strains which they must withstand, the result appears satisfactory, but experience shows that the excessive vibration at high speeds will cause crystallization of the steel and a high factor of safety must be employed.

The wheel journals should be at least 5½″ x 9″, and the diameter of axle between wheels 6½″, with a larger diameter through the axle gear.

The wheel base cannot well be more than seven feet, on account of the curves, but it is nearly all needed in order to obtain room for motors of sufficient size. The motor should not be supported by the truck frame in any way.

Steel bars should be placed at each side of the motors extending from one axle to the other, and beneath them, just inside the wheels. These should be suspended from lugs on the motor frame by suitable links as near the center line of each axle as possible. The backs of the motors can then be carried on these bars by means of other lugs on the motor frame and springs above and below the lugs. This method of motor suspension is rapidly coming into general use and it has many advantages. If motors should be damaged it is simply necessary to place another pair of wheels and axles with other motors in the same truck frame. The motor cars ride much easier, or practically the same as before they were equipped with motors, due to the fact that the jarring of the motors is not transmitted to the car body.

The motor car must be wired for, and furnished with a suitable number of electric lights and heaters, which is a simple matter. The same thing must be done for the coaches it is proposed to haul. The latter should also be equipped with collecting shoes connected by a wire which terminates at each end in an electric coupler of sufficient capacity to supply the motors on the motor car if necessary. The motor car is supplied with the regular air brake apparatus used by the road and piped as a steam locomotive, except that the car is double ended and requires an engineer's valve, gauge and other necessary parts at each end.

The independent motor air compressor, main and auxiliary reservoirs, car wiring cables, main wires for collecting shoes, rheostats and electric couplers, all go under the car in addition to the standard equipment of a passenger coach.

A small cab should be provided at each end for the motorman preferably inside the car, fitted with a front and side window which can be opened to their full extent. Here are located the air brake valves, the automatic governor and switch for the compressor, the motor controller, main switch, circuit breaker, electric light and heater switches. The bells or gongs, pilots and whistles at each end complete the list.

A few words about car wiring may be of interest here. The most careful work in wiring cars is very essential. The author believes that the causes of nearly all the fires occurring in motor cars can be traced to defective wiring. There is no reason why such wiring can not be made safe. Even if the insulation of wires and cables is of the best, they should be treated as bare wires, as the insurance underwriters say, and unskilled labor does not pay in this part of the work. The maze of iron pipes, rods and braces, under such cars, render it necessary to protect the wires from rubbing or chafing with the utmost care. It must not be taken for granted that the pipes, etc. remain in one position when the car is under headway. The working and straining of the car body, the swing of the trucks and brake rods and compression of springs must be carefully considered, and no care in protecting the wires however great can make them too safe. In trolley cars the removal of the pole from the wire will put out, or render a fire easy to control, but in such cars as are under discussion, I have not yet seen or heard of a method of cutting off the current at or near the contact shoes, though there may be such. It is evident therefore how helpless a train crew is when called upon to put out a fire caused by a terrific arc under the car. It has been proved in practice that good car wiring practically prevents such accidents. Before leaving the equipment question, I will give some opinions on the performance of the motors.

For such short distances, and the intermittent work required, the modern railway motor seems well adapted. It can be overloaded, 100% frequently, without injury, for a short time. Most types of these motors have but one or two serious faults. One is lack of sufficient ventilation. During hot weather this becomes a serious matter, and one that should be corrected by the manufacturers. The design of the axle bearing, is another. In street car work, the plan of using a gun metal lining in halves, lubricated by grease or oil is fairly satisfactory, but where these bearings each become 15″ long and 6½″ diameter; at speeds of 40 to 60 miles per hour, the conditions are different, and while giving little trouble, the cost of repairs seems unnecessarily high. Most of the motors are similar in design to the ordinary street-railway motor, entirely enclosed by the frame, and intended to run in the mud and slush of a city street. On the other hand a steam roadbed is usually dry and clean, the motors are further above the ground, and water rarely flies above the axle. It would seem therefore that they could be more open on top. It has been found necessary to run through the hot summer months with the large covers over the commutators removed. The construction, and especially the insulation of armatures has reached such a degree of perfection, that a burn-out is seldom heard of in the larger motors.

I have had under my personal observation a considerable number of such motors, some of which have been in service over two years, making a daily mileage of over 300 miles, and have never had one armature burn out. In one case a pair of motors were in service eight months, including a winter. No repairs whatever were made during that time, beyond the ordinary daily inspection, cleaning, and renewal of carbon brushes.

In another case a pair of motors made upward of 100,000 miles after being put into service, the only repairs being renewal of armature and axle brasses, gears and pinions. As is well-known a frequent cause of burn-out in the past has been due to the wear of the armature brasses allowing the armature to strike the lower pole-pieces. This cause has been eliminated by making the clearance between the pole-faces and the armature slightly greater, possibly at the expense of an increase in weight of copper on the field magnets, and with no apparent loss in efficiency.

The total weight of a 60-foot standard coach equipped as a motor car with two motors will be about 80,000 pounds, without passengers, of which 55,000 pounds is on the drivers or motor truck. The speed of such a motor car running light, if geared sufficiently high, is probably only limited by its weight and the quality of its track and road bed. With a stone ballasted track, 100-pound steel rails, few curves, and those of long radius, a heavy car with the best steel tired wheels should run 100 miles per hour at full speed without difficulty.

I have mentioned a four-motor car consisting of a 60-foot car body weighing 100,000 pounds complete. This represents about 800 H. P. nominal rating of the motors at 650 volts direct current, and this is the maximum H. P. that can be placed under a standard coach, on trucks and wheels which do not necessitate any other changes in the existing standards of steam practice. The motors are capable of exerting double that power for a short time. The total cost of converting a standard coach into a motor car with two motors is about $3,800.

The third method of using electric traction in steam service, that of the use of light motor cars and trailers, built for the purpose, has some advantages. The former coaches can be used elsewhere on the system as are the locomotives. The smaller, lighter cars are cheaper to construct, the wear on the track is less, and there is considerable economy in power. It has been proposed, and no doubt will come, that such cars will run through the principal street of a city, on the existing street car track, before starting on their trip over the steam track. This would necessitate either a trolley wire over the steam track, instead of a power rail, or both collecting shoes and trolley pole on the car. There is no question but that this may prove a great advantage in time. On the other hand, the cars must be used exclusively on the line equipped with electric power. At speeds of 50 to 60 miles per hour which *must* be made in order to compete successfully with the existing parallel trolley lines, the cost of maintenance and repairs due to the excessive vibration will undoubtedly be greater than that with standard coaches.

The economy in power due to the reduction in dead weight hauled is of considerable importance, not only on account of the smaller amount used, but the line conductors can be lighter, greatly reducing their cost, or the system can be extended to longer distances at no more expense for transmitting the power.

In the future there may be a decided tendency to reduce the weight of electric trains. In other words, it will be an attempt to handle a constantly increasing traffic with a lighter equipment in order to haul less dead weight per passenger. The engineer who proposes to introduce such changes must move with the greatest care in order not to save the weight at the expense of strength. It should never be forgotten that the maximum load is "no standing room," that the strains on a car and its trucks running at 60 miles per hour over a steam track which may be made of 70-pound rails with joints none too good, are not to be compared with such as are met with in a city street at low speed. An interesting problem in connection with a similar equipment has arisen within the last few years, and the time is rapidly approaching when it must be solved. It relates to the difference between the wheels of street cars and the steam railroad coaches. Though both use the standard gauge of 4′-8½″ the average street car wheel has a tread 2½″ wide and a flange ⅝″ deep, while the Master Car Builders standard requires a tread 4″ wide and a flange 1⅛″ deep. The problem is a serious one, for it intimately concerns the safety of the train. The steam railroad people after 50 years experience have settled upon the above standard, and the electrical engineer who chooses to ignore their experience in this, and in many other cases, runs a risk. There should be no doubt that it is unsafe to run the small street car wheels at high speeds over steam railroad tracks, with their present form of frogs and switches; and it is, in fact, impossible to run them on steel rails weighing 90 to 100 pounds per yard on account of the wide spaces in the frogs. The question may be asked: "Is it not safe to run such narrow wheels on the steam track if the latter be kept carefully to gauge, and proper frogs for these wheels are substituted for the existing ones?" If this is done steam trains can no longer run on the road, and, as it is necessary in order to round a curve at high speed with safety, to spread the gauge from ¼″ to ½″, the danger is greatly increased. On the other hand, the Master Car Builders' wheels cannot run on the existing street car tracks in our cities. The flange is too deep for the frogs, the size of the groove on the inside of the straight rail is larger than the city authorities would sanction, and the outside portion of the tread would in many cases run on the pavement and crush it down to a level with the top of the rail. The only solution of the problem seems to be a compromise wheel with about 3″ tread and 1″ flange. Whether or not this is safe, only time can tell.

The fourth question, that of hauling freight by electric power, should, of course, be decided upon at the time of installation, as it may cause considerable difference in the plans for power stations and line transmission. As the question can only refer to local freight along the line electrically equipped, it is of doubtful importance as applied to the conditions under discussion. If the freight traffic on such lines be sufficiently heavy to necessitate the use of a locomotive for several hours daily during the hours between midnight and morning when there are few if any electric passenger trains in service, it is economy to use an electric locomotive, for it costs but little more to run the power station, if it has been shut down, and the total expense would be somewhat less than that of a steam locomotive. The whole question of transportation of freight by electric power is one which concerns the future more than the present.

When the time arrives that long distances are electrically equipped on our steam railways, then it becomes far more important.

POWER TRANSMISSION.

Feeders:—The transmission of electric power forms the most important part of the problem of the electrical equipment of a steam road. At the present day our railway motors all require the direct current, and we are therefore limited to its employment in the working conductor. By increasing its voltage from that usually employed to 700 volts, a considerable advantage is at once gained, and without additional expense in motors or generators. Experience has shown that the economical radius of operation of a power station generating such a current and delivered to the line without feeders is from 10 to 12 miles. This refers to a heavy train service with a fairly frequent schedule, and an average load of 500 amperes on each radial line of single track.

By the line or working positive conductor is here meant a steel rail of 90 to 100 pounds per yard, well bonded, and equal in conductivity to about 1,200,000 cm. of copper. The statement, "without feeders," may be wondered at, and a few words of explanation will be necessary.

It should be remembered that the conditions are very different from a street or elevated road. There may be only two, or at most three trains running. The greatest fall in potential occurs when a train is leaving the further end of the line, and this may be somewhat less than $\frac{3}{4}$ of a volt per ampere at that point, while the average efficiency of the line is over 75%. Again even if the loss in the line becomes greater through an attempt to increase the number of trains, or to extend the line, the question of feeders depends almost wholly on the cost of fuel. If the interest on the cost of feeders is greater than the saving in fuel consumption effected by their use, and a satisfactory train schedule can be maintained without them, it cannot be in the interest of economical operation to provide them. It has been said that such feeders in connection with a so-called booster used to overcome the drop in the feeders, and a consequent decrease in their weight, are the most economical. Such an arrangement is undoubtedly cheaper as regards first cost, but I have seen no data showing the cost of maintenance and depreciation of these additional machines, as compared with the cost of a feeder of sufficient weight to perform the work without the booster, and on which there is practically no depreciation. Whichever method is followed, the cost of feeders for such a road will reach many thousands of dollars, and railway managers will make the most rigid investigation of traffic conditions, present and prospective, before deciding upon such an outlay.

The above statement should make intelligible the reason why 10 or 12 miles is considered the maximum radius of operation of a station delivering 700 volts direct current. It is hardly necessary to add that a larger system extending over greater distances should be supplied by multiphase generators, and a high tension transmission line combined with the usual rotary converters, located at suitable points on the system. In the absence of a practicable alternating current railway motor, the above system is the only one—there is no choice.

In regard to the most economical material to use as feeders, the extremely variable prices of both copper and steel, renders it difficult at present to come to a satisfactory decision, but with both metals at what we may call their normal values, steel is cheaper and more satisfactory. The author believes a proper feeder for 700 volts direct current should be made of flat steel bars about 1″ x 5″ section, two of which are placed side by side, bolted together with alternatad joints and supported on edge in the slotted tops of small posts set in the ground at the side of the road bed, not over two feet high and boxed in. At grade crossings the break in these feeders must be bridged by either an underground or overhead connection. In yards and stations where there is a multiplicity of tracks it will be frequently necessary to carry them overhead for considerable distances. Copper is of course used in such cases.

The Working Conductor—In considering a train service consisting of heavy trains running at the speeds mentioned, the trolley wire as a working conductor will probably not come into general use, although it is used for such a service to-day. The cost of construction, maintenance and depreciation is greater than that of a third rail. It has few advantages, and many disadvantages for such a service. It is now generally conceded that an insulated rail placed close to the track answers all requirements, and the author's experience shows that it is satisfactory. It is difficult to understand, however, why the common form of T-rail is so generally used for this purpose unless it is due to a desire to save money by using up old rails. A more inconvenient cross-section for thorough and efficient bonding could hardly be selected. It will be admitted by all that this conductor should be so bonded that when worked at its full capacity there should be no greater loss at the joints than elsewhere. There are a number of standard commercial forms of rolled steel which are no more expensive than T-rails that are well suited for this purpose. A form that will permit the use of one or more thin copper plates of ample area of contact held at the joints between a steel splice plate and the conductor by heavy pressure obtained by the use of a sufficient number of bolts, is an inexpensive and satisfactory bond. The rule that the bond shall be equal in carrying capacity to the conductor, and the area of contact equal to or greater than the cross-section of the conductor is a safe one to follow.

One question which has been studied with care is of great importance in this latitude, and that is the effect of ice on the contact surface, and how to get rid of it. Many experiments have been tried, and few can be said to have been successful. A further possible advantage of the use of some other form of rolled steel might result in the complete elimination of this trouble. I refer to the collecting shoes having a side or under-running contact. This would allow the partial roofing over the conductor by wood, which would thoroughly protect it from the weather.

Ordinary snow-storms and even blizzards do not interrupt the service. I have seen a storm which tied up nearly every wheel in a nearby State, but the electric service was the last to succumb, and even then it was not on account of the conductor rail, or too much snow on the roadbed, but from a train running off an ice choked frog. It has been demonstrated that motor coaches equipped with proper steel brushes for the third rail and snow plows, can go through as much snow as an ordinary passenger locomotive. Their great advantage lies in the fact that they can run through deep snow slowly, due to the enormous torque of the series motors and the absence of reciprocating parts. But when the temperature of the conductor rail is below freezing point, and it begins to rain, as is not infrequently the case, a coating of ice forms on the contact surface which closely resembles enamel. No mechanical method has been found to completely remove this.

As to chemical methods, certain roads can and do use salt or brine. It is not considered advisable to salt the road bed of such a road as is under discussion owing to the danger of leakage should the track become flooded with water. When applied at the right time, an oil which does not solidify at a low temperature is sometimes successful, but the difficulty of applying it to the whole road at the proper time can be appreciated.

Insulation:—The question of insulating the positive rail of a 700-volt grounded circuit has in actual practice been developed to such an extent that the results obtained are remarkable, to say the least. If such methods as are now in use had been proposed ten years ago, they would have been regarded as impracticable.

For years it was the custom to consider the ground a conductor of electricity. It was of course realized that the service rails must be bonded in some way, but the ground was considered to be a great aid to the rails in returning the current. I do not propose to deny that this is true in a crowded city where there are thousands of tons of iron pipes buried but a short distance beneath the rails, but can we call this a ground return? My experience shows that the road bed of a steam road consisting of sand, gravel or rock ballast, when dry, is a good insulator, and when wet there is but little difference. A rock-ballasted track in particular needs no insulation whatever except the wooden ties.

I am aware that such a statement may be regarded with doubt, but perhaps it can be made clearer if we take all things into consideration. The road runs through an open country, the soil is of the average composition, some of it wet, but most of it dry. If we stand on a wet spot and place our body in circuit from positive to ground we receive a shock, perhaps of maximum voltage. This would apparently show the ground to be a conductor, but a little thought will prove that it conducted a few milli-amperes only. If we stand in dry earth or on a tie, we feel no shock. But the one test that proves the insulation of such a line is the leakage test. From tests made every night, for over a year, the leakage averages ½ ampere per mile in dry weather to 1½ amperes in wet weather, and I am convinced that nearly all of this is in the underground work necessary at grade crossings and switch points. The above refers to a rail insulated upon creosoted wood blocks attached to the ties. A complete covering of snow, has little or no effect on the leakage. The form of the positive rail may influence the leakage somewhat. For example, the inverted V form acts as a roof to shed water and keeps the contact surface between the block and rail dry. But there is in use several miles of ordinary T-rail as a positive conductor, laid on blocks of wood 1½″ thick attached to the ties, not creosoted, but dipped in an insulating compound. No leakage is noticable here. We can easily understand that if any appreciable amount of the current in amperes should leak through these blocks whether prepared or not, they would burn up. The writer, therefore, believes that such insulation of the positive rail for the current and voltage under discussion is ample, and much expense can be saved by steam roads by its use.

Track Bonding.—One of the most necessary and at the same time expensive parts of the work in changing existing steam roads into an electric line, is the bonding of the service rails. The author believes he has done some of the heaviest bonding in the country, and is of the opinion that there is no satisfactory method of bonding a T-rail at present. When such bonding costs two dollars per joint, it becomes a very serious matter. Bonding around the angle plate with the bonds about two feet long, is out of the question, for the cost of copper would be too great, and it would be exposed. Riveting the lugs on the bonds through the web of the rail, is not good practice, because to secure sufficient area of contact four holes would have to be drilled in the ends of each rail, which so weakens it as to render it unsafe. The shortest possible bonds should be used under the base of the rail. It requires four one-inch holes in the base of each rail, and we can easily see how unsatisfactory and expensive this is, with four bonds of 300,000 cm. area for each joint of 100 pound steel. In nearly all rail bonds the principal resistance is in the contacts. It is a simple matter to use sufficient copper, but to secure a proper contact is a difficult problem. The bonds must have the utmost flexibility to withstand the vertical motion of the rail ends, and even then many of them will gradually break off strand by strand. What is urgently needed at the present day is a cheap and efficient bond for a T-rail. Such a bond, to be satisfactory, must show no greater fall in potential than an equal length of the rail itself, when the maximum current is flowing through the joint. On account of the fact that the ground is practically of no value in augmenting the conductivity of the return circuit, the entire circuit must be regarded as metallic, and the ground should not enter into any calculations.

Power Stations.—The writer does not propose to enter into the subject of the design and arrangement of machinery in a power station for a steam road, as there are no engineering features which differ from those encountered in such a station intended for a large street railway. An abundance of water and cheap fuel are of course important points. Such power stations can be built for from $80 to $90 per kilowatt, exclusive of the land.

A few words about the amount of power required may be of interest. An important figure is the amount of power delivered at the switchboard per train mile. It eliminates all losses due to resistance of circuit, and current used for air compressors, electric lights and heaters. This figure will vary from four to six kilowatt hours per train mile, reaching its maximum in December and January, due to the longer hours of lighting the cars, the constant use of electric heaters, and the frequent running through snow.

The question of heating a standard coach by electricity is one that should be thoroughly understood. Street car heating is totally different. The public demands the same temperature as is furnished by steam, which is 68° or 70° F. It makes but little difference what heater is used, provided there are enough of them. One may radiate its heat faster than another, and so raise the temperature of the car more rapidly, but it will require, in any case, from 12 to 15 kilowatts of energy for each coach. An ordinary train consisting of a motor car and two coaches weighing 200,000 pounds, will require, at a speed of 35 to 40 miles per hour on a level track, about 125 kilowatts, or about 166 H. P., of which the motor car alone would consume 75 K. W., if running light. The motor will consume an average energy of four to five kilowatt-hours per train mile, or 40 to 50 watt hours per ton mile. Power can be produced with condensing engines and fuel at about $2.30 per ton, for about .008 ($\frac{8}{10}$ of a cent) per K. W. hour.

Cost of Operation:—It is most desirable in operating a heavy electric service over a railway on which steam trains are also operated, to arrive at a satisfactory conclusion as to the comparative cost of operating each type of train per mile. If an electric service is entirely substituted for one which has been operated by steam, the railroad company is in a position to know accurately the difference in cost of the two systems. But when both are operated over the same tracks the problem becomes very complex. For example, even if we omit the maintenance of the road way, which may be a little higher in an electric service, there are many other items such as salaries of agents, ticket sellers, gatemen, etc., all of which properly belong to the operating department, which must be proportioned between the two services. It may be said that the cost of operating a steam passenger train has been estimated all the way from 30 cents to $1.00 per mile depending upon the length of the train and other conditions which are seldom alike in the different localities. The author cannot go into this subject in detail, but will give a few points of difference between the two services upon which an approximate estimate can be based. A fair average cost of running a steam locomotive, including fuel, when coal is about $2.30 per ton; water, wages, repairs etc. is 22 cents per mile. The average cost of repairs to coaches may be taken at one cent per mile each. The wages of train crew, consisting of a conductor, baggage master and one brakeman will average .05 per mile making a total of 30 cents. This figure is intended to represent the lowest possible cost of operating a train of only three cars by steam with the understanding that it is kept almost constantly moving for about 9 hours, and covering from 150 to 200 miles. It is well known that a train making but a few miles per day cannot be run at a profit, either by steam or electricity, due to the fact that cost of wages per mile increases rapidly, as the crew has to be paid the same in either case. A great advantage of the electric service may be mentioned here. The above service is all that can be required of one crew and one locomotive, but the motor car can easily make 300 to 400 miles in 18 hours, and as the daily service is in operation at least that long, one motor car does the work of two locomotives. In the operation of a similar three-car train in which one car is a motor car, we will assume the same crew with the addition of a motorman and omit the locomotive. The cost per mile in wages will then become 6½ cents, that of repairs to cars the same as before, 1 cent, maintenance of motors, ½ cent and cost of power delivered to train, 6 cents, making the total cost per train mile, 14 cents for the electric service.

ELECTRIC LIGHTING.

All steam roads, which have introduced electric motive power, will consider the question of lighting their passenger stations and freight houses along the line. It will be found that lighting in this way is very satisfactory and far cheaper than the purchase of gas or electricity from others. For lighting freight sheds, platforms and other outside lights, the simple wiring of the lights in groups of five or six in series, and connected directly between the feeder or working conductor and the service rails, has been found satisfactory. The occasional interruption of the current due to the opening of a circuit breaker will shut off these lights for a few seconds, which makes them inconvenient for indoor lighting. For stations requiring not over 60, 16 C.P. lights, a small storage battery of 58 cells, together with a rheostat and switchboard with the necessary switches and instruments can be installed for about $900.00. By making the rheostat of about 55 ohms resistance and 35 amperes capacity and connecting it in series with the railway current, it can be used to charge the battery.

The battery and rheostat are connected in parallel with the lighting load, and the resistance so regulated that the railway current does the lighting, the battery merely acting as a regulator, charging slightly when the voltage rises and discharging into the lighting circuit when the pressure falls, due to the movement of the trains. This maintains a practically constant voltage of about 120 on the lighting circuit, and the battery does little or no work except when the power station is shut down. The principal advantage of this arrangement is that it is practically automatic in its action, and requires no regular attendant. The station employes can handle the switches when necessary to turn on or off the lights. An occasional inspection of the battery is all that is necessary. The cost of such lighting is much less than it can be purchased from lighting companies. In larger stations requiring several hundred lights, a motor generator can be used instead of the rheostat and connected to the battery and the load in exactly the same way. Such a plant should have an attendant.

Discussion at New York, Feb. 28, 1900.

Mr. Frank J. Sprague:—Mr. President and gentlemen, I have been asked to open this discussion, and I have been spending a part of the afternoon looking at a time table. I have listened with interest to Mr. Boynton's paper, giving the principal results of his experience on the New York and New Haven road. If I have any criticisms to make of it as a paper, it is that it does not treat of the subject on quite as broad lines as I would liked to have seen. It is more a record of what has been creditably done, with interesting results, in connection with work of the New York and New Haven Railroad, inaugurated at a time when there was a good deal of cynicism expressed. I will take the liberty, if I may, of going back to a review of this subject, and reading from lines written some five years ago, and then make reference to some projects which are now in hand. I think, possibly, I might suggest a title for Mr. Boynton's paper, something like this: "Shall electricity be used on steam railways, and, if so, how far and under what conditions?"

In the paper referred to I stated: "Electrical development will go on until the trolley system is almost as common as the turnpike. It will establish lines of communication which have not hitherto existed; it will build up new territory; it will act as a feeder to great trunk-line systems, both for passenger and certain classes of freight work; and it will largely encroach upon special fields now occupied by the trunk lines.

"But, when we depart from this class of service and take up what is essentially a trunk-line system, there are many questions to be considered, and not alone those of the local and express service, but also a most important one, which is rarely considered when electric railways are talked of. I refer to the trunk-line freight service—that is, the transportation of goods in great bulk over long distances. One must remember that trunk lines, as they now exist, have been built up by a slow process, and that no very serious change from their existing conditions can be made, considered from the commercial standpoint, except after grave deliberation and at very great expense. Unless passengers and goods can be moved over a system with increased benefit to a community, or at a reduced cost, or with a commensurate return on capital invested, an electric will not replace a steam system. Of course, in these remarks I ignore specific problems, such as the utilization of a storage battery and motor in place of a locomotive, or of a moving central station, as is being tried on one of the French lines, or those special problems like the Baltimore tunnel, in which an electric locomotive will be utilized for a short distance in place of the steam locomotive; I am considering the possibilities of what is generally considered an electric system—that is, the operation of a number of train units from a central station.

"If we were to refer a moment to any other system of transmission of power—for example, by water or air—no one for a moment would question its limitations. We all know that any amount of power can be so transmitted, but only with definite losses which depend upon the pressures used, the sizes of pipes, and the distances and amount of energy transmitted. So it is in the transmission of electricity, which is nothing more or less than an agent whose exact character we do not know, but whose obedience to certain empirical laws is absolute.

"It is unnecessary here to repeat the specific laws covering such transmission; they are perfectly well known, and there is no practical hope of their being changed, any more than the laws of gravity. Recognizing these laws, there is a distinct limitation to the distance and amount of power which can be economically and conveniently transmitted and distributed, no matter how perfect the generating or receiving machinery may be; and these two particular elements have been brought very nearly to their maximum possible efficiency.

"It may be said—which is perfectly true—that, if from a central station one can conveniently operate a number of distributed units over a 20-mile road, why cannot two or, for that matter, a dozen such systems be connected together? So they can, but this does not form a trunk-line system. Of course, if we consider the steam trunk-line from a passenger standpoint, the present system has defects, and the principal one is the inconvenience of service when considering short distances. If one is going a long distance then it matters not so much whether the trains are two or three hours apart in leaving; but long-distance travel and short-distance travel have not the same requirements so far as the passengers are concerned.

"If nothing is sacrificed, it would be preferable, of course, to have smaller units despatched at more frequent intervals, no matter what the distance of travel, but, as I say, this is less important when dealing with long distances than when dealing with short ones. When trains are operated in large units, with comparatively few units between terminal points, and these at considerable intervals, the steam locomotive will absolutely hold its own. When, however, these larger units are broken up, the intervals of train-despatching can be shortened as much as is consistent with satisfactory operation and the number of units distributed over a line made correspondingly large; then, and then only, will electricity be used on suburban lines and lines connecting important cities.

"I have again and again advanced the substance of this statement, and I must here repeat and emphasize this fact—that, so far as passenger service is concerned, considering for the moment only economy of operation, the problem narrows itself down to the number of train units operated between terminal points. Make that number sufficiently large, and the electric motor is the best means of propulsion, whether for high or low speed. Decrease this number, and you must rely upon steam.

"Or, putting it another way, the answer to the query, will electricity take the place of steam locomotives for railway service, is: only in part, and then only when the number of units operated between terminal points is so large that the resulting economy will pay a reasonable interest on the combined cost of a central-station system of conductors and the motor equipment, and the traffic existing is commensurate with the needs of such a system.

"It is perfectly true that looking only at the time standpoint of passenger traffic it is entirely possible and feasible even, not only to operate any existing street or elevated system, and many of the suburban systems, but also the traffic between such points as New York and Philadelphia on a subdivided electric service; but this is not all that is required. The more frequent the units despatched over the track, the more exclusive must be that particular track for that particular service, and the larger must be the number of tracks to take care of all the varied service of a great system.

"Briefly, the service may be characterized as the transmission of passengers from one local point to another and the transmission at high speed between principal points—that is, way and express service—and the handling of freight in great masses with all the attendant switching and distribution at way and terminal points. Considering only the transit needs of these various services, a six-track railroad might be considered desirable, and probably would be; but there are many problems connected with such a road, to say nothing of the fact that it would often be impossible to construct such a system on existing rights-of-way. Independent of the matter of investment, rights-of-way, or construction, the problems of switching, passenger landings, and freight acceptance and delivery, on a six-track railroad would be a grave one.

"Freight cannot be handled like live loads. A succession of cars, each with twenty or thirty passengers, might well take care of all the passenger traffic on a road, but freight cannot ordinarily be handled in any such way, except by an enormous increase of expenditure. The 30-, 40-, or 50-car train, pulled by a single locomotive, with a limited train crew, presents an economical transportation of freight which no system of units on long-distance transportation can hope to equal.

"It may be contended that there is a way to create a six-track service, and that it can be operated partly electrically and partly by steam, and that the small units for way service can be run on one set of tracks, the express units on another, both subdivided, and that larger freight units at long intervals can be operated on the third, but this proposition will not appeal with any practical force to the railroad man, or to the electrical engineer as such, because it is absolutely vital for successful electrical operation from a central station that the units shall be divided, and that there shall be a distributed service, and not a localization of large units at long intervals at any portion of the system.

"It seems hardly necessary to even refer to the question of signals, and all the difficulties which would exist if an attempt were made to operate a road simultaneously with electricity and steam. Human life and its absolute dependence on these signals, which neither natural laws, stress of accident, or conditions of weather should interfere with, make this of vital importance in considering any change.

"One of the great advantages of the electric system, as generally used, considered from a traction standpoint is the fact that the motors are carried under each individual car, or, with few exceptions, under one of two or three cars, thus giving the advantages of a higher proportion of weight for traction, with a consequent distribution instead of localization of weights. When motors reach their highest standard every car can be made an individual unit, which can be operated in any combination and from any point of a train; but this advantage instantly disappears when it is attempted to use an electric locomotive after the manner of a steam locomotive. That is, to put it ahead of a number of car units whose aggregate weight may be from five to twenty-five times its own. It must, then, in a large measure be limited by identically the same laws in the matter of weight and traction as the present steam system. Assuming units which are common on steam roads, such as 1000 or 1500 H. P., the enormous loss of energy and the variation of pressure on a line would make the cost, with any possible allowable loss, entirely impracticable.

I have seen little development in the last five years to alter those general conclusions, but I am no less a believer than ever in the gradual and certain encroachment of the electric upon steam railways. If I were asked, however, if electric traction will take place "under steam railway conditions" I would say no, except in special cases. What are steam railway conditions? A more or less perfect roadbed, which gradually becomes a more or less exclusive roadbed, and the more exclusive it becomes the better it is for electric railways; stations at predetermined positions and distances of signaling; operation on the same or on separate tracks of express and local service and freight service, which complicates the problem; operation under a fixed time-table, with varying lengths of trains, but always large units, with a tendency to larger ones. These are essentially steam railway conditions. Many of them are directly opposed to commercially successful electrical operation.

There are two things which have been brought forward and practically developed in the past three years which are not mentioned by Mr. Boynton as having a possible use in future electric railways. The first is the storage battery. Its use on the South Side elevated in Chicago, on which I have 180 cars in operation, the experience on the Metropolitan road in this city, and the general introduction on a large number of other roads and central stations, primarily for the purpose of equalization of load and for taking a small portion of the peak load at certain hours, warrant the statement that it is certain to be a feature in railway development. There is no doubt in my own mind concerning this. Another development is the method of controlling two or more units or cars equipped with motors from a common source, which I have called and it is now known as the "multiple unit" system, subject to more or less ridicule and criticism during past years, but now being generally accepted as necessary in modern transportation. I do not mean by the term "multiple unit system" the equipment necessarily of every car in a train, but the equipment of two or more cars of a train under a simultaneous control. Neither of these developments are mentioned or considered by Mr. Boynton. If there be a question about this latter proposition, let me recite what has been proposed with eight or ten roads representing modern work. The Illinois Central Railway, with its six or possibly eight-track service, stands as an example to-day of the most perfect steam suburban service. For two years and a half at least actively, and for four or five years before that tentatively, its management has considered the application of electricity to that suburban service. Bear in mind that before we undertake the larger problems we must take that which is at hand; that is, suburban service 20 or 30 miles out of the city. So we will consider this Illinois Central road. The conclusion arrived at some two and a half years ago was that from the standpoint of steam economy nothing whatever was to be gained by the adoption of electricity under the conditions which exist in Chicago on that road at the price they paid for coal and with the duty they are getting out of the engines; that in the matter of speed, that was already very satisfactory on the express service, but for the way or suburban service electricity offered an advantage, permitting an increase from 18 to 23 miles schedule speed. But all consideration of a locomotive or a locomotive-car pulling a number of cars has been put aside for a finality. The only thought, I think I may say fairly, which they have had in mind is one expressed by the then Chief Engineer and now Assistant First Vice-President Wallace, when he said in effect to me, some two years and a half ago, that he wished to see the abolition of the time-table on suburban service, and to be able to direct at frequent and regular intervals the going out of train units of one or two or ten cars, without unnecessary switching, without a locomotive at the head to pull them, motive power and capacity always holding like proportion to each other, with orders to leave the terminus and get back there as quickly as possible, without waiting at any station for the time-table. He said: "I hope to see cars operated by a push-button." It happened at that time that I was in Chicago, connected with the Chicago South Side elevated, and I told him that that was what I was there for. Shortly after that the equipment of the South Side road was taken up. If that road adopts electricity they will put on their cars not less than 300-horse power, and those cars will be operated in any combination from one to a dozen cars. Such radical operation requires, for the best duty, a storage battery to help equalize the load and to take perhaps a little of the peak. If alternating currents are used, with rotary transformers delivering constant potential on the line, it is out of the question to put upon the sub-stations the sharp, varying loads which would be required, without a storage battery.

The Liverpool Overhead Railway operates at present three-car trains, with motors on the front and the back car. The Waterloo and City Railway of London operates three and four-car trains, with motors on the front and back car. The Union Electric Company of Berlin has recently submitted a project to the Minister of Public Works proposing the change over from the present steam system to an electric system, working as many as 12 cars in a train, each car being equipped with two motors of 150 H. P. capacity each. The new Berlin Elevated Railway, of which Messrs. Siemens and Halske are the prime movers, are considering the operation of four and five and even up to ten-car trains, and they have had under consideration all sorts of methods—four-car trains, with three motors on the front and on the back car; four-car trains, with four motors on the front and back car; five-car trains, with two motors on the front and back car; ten-car trains, with two motors on the first and rear car and two motors on a middle car, and a full multiple unit system.

The new Boston Elevated road will have an equipment of two 150 H. P. motors per car and operate them in from two to five or six-car trains, all under a common control. The Manhattan—well, none of us can speak with any definiteness about that yet, and therefore I will not prophesy.

The Brooklyn elevated will operate from three to five-car trains, with two and three motor-cars in a train, and contemplate eventually equipping every car, all under a common control. So it would seem that in electric railways the idea of grouping together units and controlling them from a common point is the accepted engineering conclusion, no matter who does it or what the specific apparatus. If a railroad is operated either with one-car units or two-car units or six-car units all the while there would be a definite determination of the motor equipment for that unit. If instead of being constantly operated with one size train units, it is operated with trains which are made up of a varying number of units, then it seems reasonable to suppose that each of those units should be equipped with the power and only with the power that is necessary to drive them.

Some of you are suburbanites. I am not, except as to my shops. The advantages (or disadvantages) of New York are such that to get out we have either to burrow or float, go through a tunnel or go over the water, and I have often to take the Delaware, Lackawanna and Western Railway. I picked up a timetable this afternoon, and I was a little surprised at some of the conclusions which a graphic setting out of that time-table showed. You know that from Hoboken there is a two-track stem with some freight sidings that runs to Newark and up to the Roseville Avenue Junction. Thence a branch goes to Montclair. From Roseville avenue the main stem of the road runs out to Summit, Morristown, Dover and on. Taking the latest time-table, I have laid out the trains on a graphic method, based on number of trains and times of transit. The distance from Hoboken to Roseville Avenue is about nine miles, thence to Montclair four miles, and from Roseville avenue to Morristown 21 miles. This road may be taken as typically representative of a suburban service, and is right at hand. At present one crosses the ferry every 10 or 15 minutes and finds a train every 40 minutes or every hour and 10 minutes, just as one goes on the Manhattan elevated to 155th street and then finds trains to Yonkers anywhere from 10 minutes, to an hour and 10 minutes apart. The aggregate roadway here considered, is roughly 34 miles, and the actual single trackage about 66 miles. Between about five o'clock in the morning and one o'clock at night there are 144 trains in operation on either a part or the whole of the distance over those lines from Hoboken to Montclair, or to Morristown, 31 miles away, leaving out those trains which go beyond Morristown. I have considered their limit of service because it is within the reasonable limits of transmission of an alternating current from a reasonable center. Perhaps it would surprise you to know that despite that number of trains there are times—considering no stoppages whatever at a station, but only the time from departure to arriving—between five o'clock in the morning and one o'clock at night when there is only one train on this 66 miles of track. That is a steam railway condition, but not one which will ever be adhered to if the road adopts electricity. Considering the stoppages of trains at the different stations, there are probably not less than 20 times during these hours in which there is not a car moving in all those 144 trains that operate within the 30-mile radius of Hoboken—not less than 20 times within the day when there is not a wheel turning on 66 miles of track, despite the fact that this road is supplying 20 or 25 populous suburban towns. It has been said that that road is considering the adoption of electricity. It is a perfectly practicable engineering problem and entirely feasible commercially. As at present run there are but from 1 to 13 trains in service, and from about 3 to 65 cars maximum. The equipment to get the best service should be with not less than one-half of its cars equipped with motors, and I question

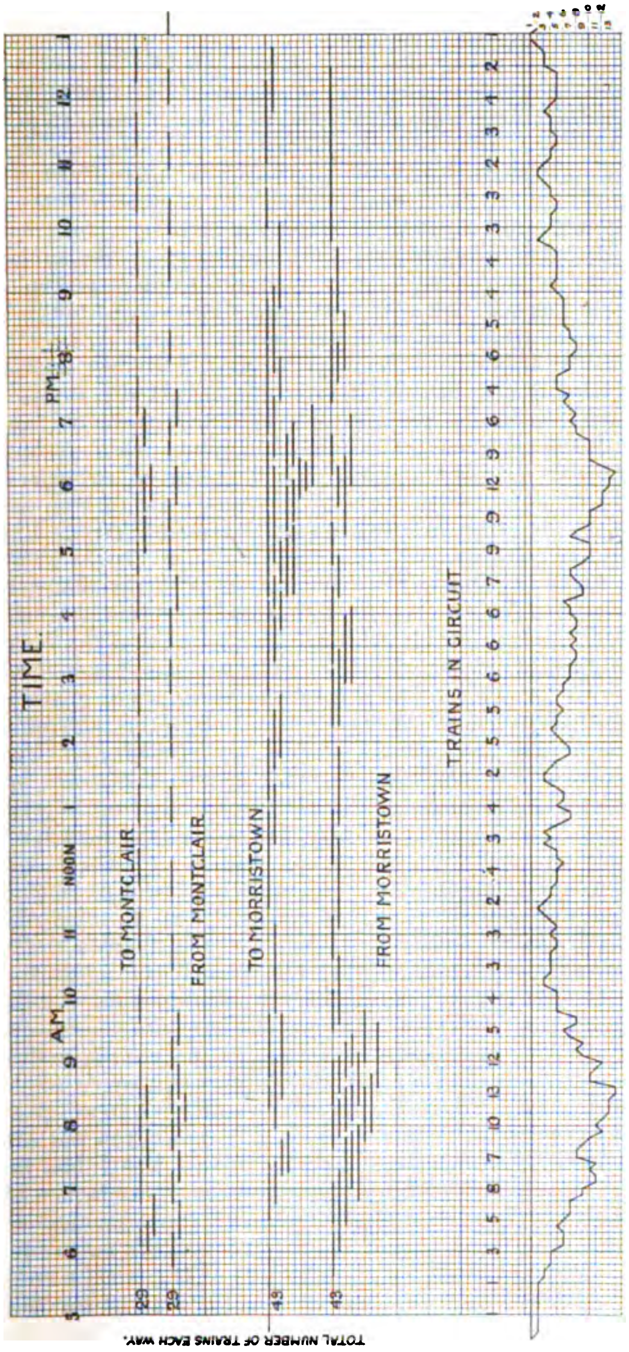


FIG. 1.—Train Time Diagram, D. L. & W. R. R. Suburban Trains to Montclair and Morristown, and Between.

if it would not be better if every one of its passenger cars were, but certainly not less than one-half.

There are two things you have got to consider in traffic. One is to meet the wants of the individual man. He cares little what anybody else wants. He goes to a station and wants to go home or to business. The other is to meet the collective wants of these several men. Scattered throughout the day there is a fair average of people who wish to travel, and at certain hours of the day there are large numbers of people who have a similar desire. So we have to consider not only the frequent dispatching of trains, but the variation in size of those trains. If one-half of the standard coaches on a road were equipped with motors under conditions that would make it possible to operate two or a dozen cars under simultaneous control, the cost of the car equipments would probably not exceed one-quarter the cost of a single one of the generating units required for the Manhattan Railway, including its engine, steam piping, and proportion of building. The power required to operate this 34 miles of suburban road would be equal to about two of the Manhattan units, and but very little more than is being used on the South Side elevated in Chicago.

It seems to me that the broad question of using electricity on a road is one which is to be determined absolutely by the frequency of service which that road will stand, and the more the short-distance trains are operated electrically the fewer the steam trains going to long-distance points, which must operate over that road. I will content myself by simply prophesying two facts: one is that the storage battery is a necessity in any large development of the application of electricity to railroads, and the other, that the aggregation and control of two or more units in a train—that is, the multiple unit system will be the future method of operation.

DR. CARY T. HUTCHINSON:—I think Mr. Sprague has entirely misunderstood the intent of this paper. I do not think it is intended to discuss broadly the most economical method of operating trains by electricity, but was intended as a resumé of the author's experience in handling suburban trains; and it tells what the author has learned. There is no intimation whatever in the paper that any consideration of the economics underlying electric railway service was intended; but there are many interesting results of his experience; among others, the very low cost of repair of electric locomotives, only ten per cent. of that for steam locomotives. I do not think this would hold as an average result or even an approximation. The figure of four to six kilowatt hours per train mile for train service without mentioning at all the weight of the train or the schedule is indefinite. It is generally understood that the energy consumption per ton-mile may vary in the ratio of 1 to 10 for different schedules.

There are a number of other facts of that kind that might be discussed, in particular, the performance of motors, etc., for above ratio. What is the ratio?

Mr. George T. Hanchett:—I note in the paper that Mr. Boynton mentions an 800-H. P. equipment of four motors. That means a 200-H. P. motor. I had the good fortune to observe the experience of a prominent company manufacturing railway motors of that capacity. They were used in elevated work. They were installed within a 6-foot wheel base with a 33-inch wheel. They filled the space. There was hardly room enough for the brake rods. The motors had to be mounted on an odd angle in order to allow the car axle to thread through the casing between the pole-pieces. It was found necessary to keep these motors open both above and below the bearing on both sides in order to safely rate them at 200 H. P. If I remember correctly, the temperature rise was something like 75 degrees centigrade above the atmosphere. If those are the facts it is necessary to keep the casings open if we are to use 200-H. P. motors in such work. Such ventilation was mentioned by Mr. Boynton as a luxury which might be enjoyed under certain circumstances, but I think it is a necessity if the experience of this company is to be believed.

Mr. Richard Lamb:—Speaking of open motors in suburban service, I have recently been called upon to build a trolley line at Brigantine Beach, N. J. The ocean had cut away the beach, leaving the trestle out from the shore a distance of about 200 feet. One of their experiences was that when the tide was in and the waves were high they would have an armature short-circuited and burned by the salt spray entering the open motor. On one occasion they had one of their large generators in the power-house thrown off of its foundation, from the ocean spray short-circuiting an open motor on a car two miles from the station, the circuit-breaker having failed to work. They also had the experience of the sand blown into the open motor by the winds, cutting away their commutators and journals. They tried putting what they called a canvas petticoat around the opening of the motor. This raised the temperature excessively. These experiences prove the absolute necessity of using completely encased motors in any suburban service having seashore road-beds.

Mr. Elias E. Ries:—Mr. Boynton, in his paper, although he mentions and describes the various methods he speaks of as relating to the operation of electric railways "under steam railway conditions," it seems has confined himself more or less to short lengths of lines of about 10 or 12 miles, such as are and have for some years been successfully operated by direct or continuous currents. The application of electricity to such short lines of steam railroads I should regard as operating steam roads "under electric railway conditions," rather than under steam railway conditions. I believe that the thing which electricians and engineers in general have chiefly in mind when it comes to the question of substituting electricity for steam on railroads is the electrical operation of long lines, or trunk lines. That, it seems to me, can only be successfully accomplished when we have arrived at the point when we can supply alternating currents of high tension for transmission purposes and convert these into currents of lower tension for the operation of the motors. This matter is incidentally touched upon in Mr. Boynton's paper, but very little has been said here to-night in regard to it. It is a subject, however, too lengthy to be discussed at this late hour and I will therefore pass it by, notwithstanding that I believe the solution of this problem necessarily rests upon the adoption of such a system.

There was one interesting point mentioned by Mr. Sprague in his discussion, stating his belief that in any rotary converter system operated by high potential currents for long distances, it would be necessary to combine with it a storage battery. It struck me that there was an interesting possibility in that application when you come to the question of the general problem of operating trunk lines or long-distance railway lines with infrequent long-train service by electricity, and that is this: The great difficulty in adapting electricity to steam railway operations is that the present steam locomotives are fairly economical because they carry along their own generating capacity, which is not only sufficient for, but is applied locally to, the work of hauling the train; they require a certain crew, limited in number, and their most economical condition of operation is to haul as heavy a load as the traction ability of the locomotive can sustain. The electric system, on the other hand, which requires fixed stations for generating current that must be transmitted over the line whether there be only one or a dozen trains on a section, demands that its generators be operated at the highest efficiency—that is to say, at practically full load at all times, preferably 24 hours out of the 24, and it would be a great waste if those generators, which must necessarily be given a power capacity greater than that required to move the heaviest single train at the required speed, had to remain idle for a period of anywhere from one to four or five hours at a time between trains.

Now, it strikes me that it is just possible that a system of generating stations could be combined with a storage-battery plant in which the battery would be used, not merely for compensating for the difference between the peak of the load and the level load; but it could be charged by generators of rather moderate power running all the time, the battery groups being so connected as to give forth their energy for comparatively brief periods in large amounts (to feed long, heavy traffic trains running approximately under steam-railway schedule conditions at more or less infrequent intervals), on the principle of the accumulator in a hydraulic system, or the flywheel in a punching press, etc. In that case the current might be generated and transmitted as a continuous current, feeding, at intervals along the line, storage batteries connected in series, and the latter might be arranged to automatically discharge into the service or working circuits in multiple, at ordinary working pressures, whenever a section is entered upon by a train, and so on. I merely mention this as a passing thought—that that seems to be one way in which the existing steam-railway conditions could be maintained under electrical operation *if* it were desirable to do so. I do not advance this, however, as a desirable solution by any means, as I believe it will be found better to modify steam-railway conditions so as to conform to what has been found best in electric practice. It simply occurred to me and I thought I might mention that as an interesting possibility. The general subject is one of considerable importance, and I am very glad, indeed, to have heard the INSTITUTE discuss the matter so fully this evening.

THE SECRETARY:—There have been some criticisms on the title of this paper, and whether they are just or not, I am not certain that it should be left for the author to defend, because whatever the title is, it was originally suggested to him, and then after he adopted it, it was changed; and, as a matter of fact, I do not think he is responsible for the title at all. What this is, and what it was attempted to get, is some notes or some information in regard to the operation of trains by electricity, over the same road and under the same conditions where they had previously been run by steam. Perhaps some of you may be able to fit a title to those conditions, for that was what the Committee on Papers was trying to get at, and it went to the only known place in this vicinity where electric trains were operating under those circumstances.

There are certain interesting questions involved in such a radical change of operating conditions as noted in this paper. I served on a railroad for two years before I went into telegraph work, and I have ridden on a steam railroad as a suburbanite for 33 years, and I can speak as a practitioner in early days, and an interested observer of modern methods. I have recently had an opportunity of comparing a steam express service with a fifteen minute interval and a trolley occasionally connecting with it on a twenty minutes headway. But the superintendent found that they could not quite make the schedule under all conditions. He said that if things were all right, that they could make the time under twenty minutes headway. But sometimes things happened —cattle or old women or wagons got on the track and delayed the cars, so they changed the schedule to 22 minutes, making it 66 minutes in the hour, as you might say. It has been a problem ever since that road changed its schedule about six weeks ago for the people on the side streets to find out when a car would be along.

It appears to me that people who undertake to manage a service of that kind should study the conditions of life and the conditions under which people travel on the cars, as well as taking up the technical questions, because in this particular case there is a great deal of traffic comes on the connecting steam railroad. It is not so much the question of the time-table as it is having the cars run at regular intervals in each hour. If they run every 30 minutes and start on the even hour, you know there is one every half hour; that is all right; all that is perfectly clear and easy, and so it is when they run every 20 minutes or every 15 minutes; but when they run every 22 minutes, making a variation of six minutes in every hour, it begins to be a brain-racking performance to keep track of it.

Getting down to some of the technical points that are brought up by Mr. Boynton, he mentioned this third rail, and the difficulties of bonding with that particular form of rail, and it occurred to me that it would be a very simple matter, if there was any amount of business in this, to make a form of rail for a conductor that would be satisfactory. Then there is a question as to the position of this third rail, whether it is to be outside of the two rails or between them, or near to one, or in the center. I do not see any information in the paper as to the best position.

In regard to ice on the track, while we have comparatively little of it, it does not appear to me that this is an argument against the use of electricity. Where it is an annoyance, and in certain climates it would probably be worse than it is around here, it appears to me that it could be gotten over very readily by an economical device. Even if this could not be done, we might as well say that the locomotive is a failure, because sometimes it gets snowed in, as it does, and becomes one of the most helpless pieces of machinery that you can imagine, when it is packed in the snow. Regarding speed possibilities, I would like to inquire as to the distance required for getting up the speed of these short trains, for this reason, that a few years ago, when what was then a record run of 72 miles an hour, was made on the Bound Brook route, that train ran 12 miles before attaining that speed. I believe there is only one place on that line where the track is in such condition that they can make such time, and of course when you consider that it takes 12 miles, as it did at that time, why of course frequent stops make it practically impossible, and it appears to me that before dismissing the subject, we ought to consider this question of speed a little more, because it is very important, as some of the predictions in regard to the speed of electric locomotives have not been verified in practice. The probabilities are that one of the reasons is that there are very few lines in the country that are well enough built and have a sufficiently long stretch of reasonably straight and level track so that they can attain the speed that we have had in contemplation.

Mr. Harrison Anderson:—I came here this evening as a stranger and guest, and one of my reasons for coming was that I am browsing around everywhere. I came in search of information and instruction, and I like my instruction very much as I like my whiskey—I like it straight; and I can illustrate what I mean by an experience that I had a couple of years ago in the west, when I was trying to sell a very fast steamboat to Mr. J. J. Hill, of the Great Northern. While we were out on this steamboat together, naturally, Mr. Hill instead of talking about my steamboat was talking about his own railroad. I was very willing to listen. He said: "You can write the whole secret of successful railroad operation on your thumb nail. I have men who have been in my service for twenty years and have not got down to the fundamental facts of successful steam-railroad operation. It is that expenses are by the train mile and receipts are by the ton mile. That is all there is to successful railroad operation." I came here this evening hoping that I would hear some formula of that kind that would give me an absolute grasp of the successful operation of electricity as replacing steam on the railroads.

Mr. Sprague:—Possibly I can give the gentleman some information on that point. The South Side road in Chicago, of which I have spoken, was a steam road operated by Baldwin 28-ton compound locomotives, hauling from two to five cars. The saving at the present time is about $500 a day for coal alone. They are also saving in transportation expenses. The actual cost of the operation of the road, exclusive of taxes and licenses, is seven and a half cents per car mile of 22 tons average weight, including passengers, and stopping at intervals of about 2,000 feet, on a schedule of 15 miles an hour.

No one here has spoken of the somewhat interesting experiment made in Germany on long-distance transmission. Mr. Reichel, the chief engineer of the Siemens and Halske Company, was here a short time ago and he told me of some experiments he had carried on in the transmission of an alternating current at 10,000 volts over a small line, from which the current was taken directly to the locomotive, on which was a transformer, connected with which was an alternating current motor. His object, of course, was the reduction of the cost of transmission for spasmodic service over long distances, and with a small arc of contact to get a large amount of energy from a small overhead wire. I do not know how successful the experiment was, but it at least was tried. But on the new Berlin elevated railroad they are going to use the continuous current at 700 volts.

I notice, speaking about the cost of some things, that $80 to $90 was given as the cost of the central station per kilowatt output. The cost in the stations laid out in this city at present is over $200 per kilowatt, including engines, dynamos, switchboards and such proportion of the building as is required to cover that particular unit. There has been some rise in prices in the matter of machinery recently.

On some elevated roads ice is kept from the third rail by running a fast car or train over the lines on seeing the approach of sleet. With the more or less reliable weather prognostications, it becomes possible generally for a good weather man to state whether he is going to have sleet on the track or not, and sometimes they run over the line and grease the third rail. That is done on the Brooklyn Bridge. It is sometimes done on the main section of the Fifth Avenue road. Where there are a number of cars in operation, and the main current is carried from car to car, then the shoes on the forward car are apt to break the sleet, and those on rear cars do their duty of supplying the main current. I have seen five cars coupled together in a train on a track very heavily coated with sleet, in which the forward cars broke the sleet coat completely, and there was scarcely an arc of any kind on the brushes which made the actual connection, because there were so many connected together.

Mr. George F. Atwood:—I would like to ask Mr. Sprague or Mr. Boynton if there has ever been any other form of collecting shoe tried than the ordinary type of shoe?

Mr. Sprague:—I do not know of any that has been tried in every day use. The Union Electric company of Berlin proposed the use of a side shoe. Sleet is not always formed on the top of the conductor alone. It is oftentimes formed on the side by the wind drift. In Boston proposals were originally made for covering the tracks with a sort of shed. I don't think that will be carried out. The project in Berlin calls for a covered track, but I doubt if that will be finally adopted. Where you have a number of trains in operation and can connect cars, you can almost always overcome any sleet storm which may occur.

Mr. Atwood:—You never use a rotary shoe, a side pressing shoe?

Mr. Sprague:—Not that I am aware of. I used wheels myself as long ago as eight years, on some experiments on the Third Avenue elevated, 34th street; but the ordinary sliding shoe is more satisfactory.

Mr. C. O. Mailloux:—I would like to have Mr. Sprague explain the difference, if any, in acceleration obtained with his system of multiple control, as compared with the ordinary control system. I have understood that there were advantages claimed for it, in so much that it enables the car to accelerate faster, or to reach its full speed sooner. This is a matter of extreme importance in rapid transit, such as would be suitable for an elevated road. I had occasion to study the matter two or three years ago when they first discussed the matter of equiping the road, and discovered, much to my surprise, though it might have been easily anticipated from theory that there are limitations to the average or schedule speed (in miles per hour) which it is possible to obtain on the elevated road, owing to the limitations of the velocity of acceleration. I was told at the time that Mr. Sprague was enabled to accelerate his cars faster, and that by being able to do so he was able to shorten slightly the schedule time between two stations.

Mr. Sprague:—I will give you an exact comparison. As to curves and grades the Manhattan elevated and the Brooklyn elevated are almost identical in their conditions, and require about the same energy per ton-mile for any given schedule. On a six-car train, a schedule of about 13½ miles an hour, when the train is loaded, is barely possible with a locomotive car weighing about 40 tons equipped with four motors of the largest size which are practical to put under a car. They would be rated at 600-horse power, but that is excessive rating, considering the thermal characteristics, and they could not stand the service. If instead of the proportion of weights on the drivers that that locomotive would give, these six cars are equipped, each car with two 80-horse power motors, it would be perfectly possible to go to a 16½ mile schedule, or if equipped with two 50-horse power motors, making the same aggregate motor capacity on a six-car train which it is possible to get with a locomotive car, a 15 mile schedule can be made with the distributed motor equipment, with identically the same power at the central station as would be required to make a schedule of 13½ miles with the 600-horse power localized on one car.

If the schedule of 13½ miles were only required with the distributed motors, there would be a reduction of about a million and a half dollars in the cost of delivering current to the car-shoe.

These are briefly the results of a good many calculations which have been made with reference to roads with these particular conditions. The reason is that there are three kinds of work; lifting of a car on an up-grade, which is independent of the schedule; simple traction, which is so much per ton, and is also perfectly independent of the schedule, except as the air pressure affects it; and inertia, which is put into a car and thrown away in braking. If you can get a car up to a certain speed, cut off the current, and then coast to a stop, it would be just as well to run the car that way as to go to some less speed, then run along at a constant speed, and coast without any braking to a stop. The energy put into a car for the purpose of getting up speed varies as the square of the speed, so that the difference in inertia energy between 20 and 25 miles is as 400 to 625. Under the conditions existing on the elevated railroads here and in Brooklyn, and for quite a range of schedules, the energy per ton-mile varies nearly as the cube of the schedule speed. It runs up rather rapidly. About the most economical speed with the existing station distances stops and grades is about 16 miles.

Mr. Boynton:—There have been so many criticisms on this paper that it is impossible to reply to them all in the short time that is left. I would say that I was much interested in Mr. Sprague's address on the subject, and have gained considerable information. I am not quite able to associate the multiple unit system of control with every condition of steam railroading. But there is no doubt that for most of the suburban conditions of traffic in cities it is applicable.

The traffic with which perhaps I have had more to do than any other is not exactly similar to suburban traffic. It is a traffic that does not consist of a great many trains running on frequent schedule. If one goes to a steam railway manager and proposes to equip a certain section of his line with electricity, one can tell him all the different methods of employing electrical apparatus, but he will inquire about dollars and cents. He will place that at the bottom of every proposition you bring up. If he has a million passengers to transport from one place to another in a year and you tell him that you can do it for considerably less than it is costing, then he will listen to what you have to say with interest. Nearly every one with whom I have come in contact in railroad business emphasizes that point. Of course it is the practical place to look. That is the principal reason why a sentence in the paper reads as follows: "It is considered probable that a given number of passengers can be transported cheaper with an electric locomotive hauling a train of idle cars, than if all the cars or two or three of them were motor cars." The probability is that the total weight of the train would be less. The above statement is merely an opinion, for no tests have ever been made of the two systems, where the trains are composed of standard steam railroad coaches. It would seem as if the locomotive train would be considerably lighter as it is relieved of the weight of many motors and equipments.

I differ slightly from Mr. Sprague in one other particular. Mr. Sprague remarked that he did not think that electric traction would take place under what are now known as steam railway conditions; that is, it will not take place in the future under existing steam railway methods. I think it will have to begin in that way and perhaps gradually develop into a multiple unit system afterwards if traffic warrants it. There are a number of roads that are running under steam railway conditions; electric trains and steam trains running on the same track; with sometimes only two minutes leeway between the electric and the steam trains. A practical point brought out by one or two speakers, that the service should require no time table, is a very important point. If the trains run at regular intervals, like 5, 10, or 15 minutes headway, no time table is necessary then, and the public appreciates it.

The use of storage batteries is undoubtedly going to increase. It is going to increase in more than one way. I have spoken of a road that is run without feeders. We are at present installing a storage battery on the end of the road, connecting it right across the end of the line. The train service is such that that battery can be kept fully charged by utilizing the current when no trains are on that end of the line. Its tendency is of course to even up the potential along the line. Such a method of feeding a railroad, if you choose, is much cheaper as regards first cost than putting in a feeder of metal.

In regard to some of the other criticisms, I am obliged to Mr. Pope for clearing up the title of the paper. The object in writing it was simply to bring out a discussion of various points. As to some of the figures in the paper, I did not think it was necessary to add a foot note to the effect that an employee of a corporation, such as I am, is not always allowed to give out exact figures. Therefore, if I said from four to six kilowatt hours per train mile, and the actual figures obtained from tests with a wattmeter, voltmeter and ammeter on a train was 5.1; I prefer to say four to six instead of 5.1, and by carefully reading certain parts of the paper, it will be seen that the length and weight of the trains, under consideration are stated with sufficient clearness. When it is said that power stations are built for $80 or $90 a kilowatt, perhaps I might say that I have seen one built for $88—a large one at that, within three years.

MR. SPRAGUE:—I did not mean to say that the multiple unit system was the one system applicable to *all* conditions of railway work. A great many conditions must necessarily be met in specific cases. What I had more particularly in mind was the handling of suburban passenger service, which is the first elemental step from trolleys into steam railroad fields, and also I would not have it understood that I do not believe in the thorough practicability of operating steam cars over the same tracks as electrics. I have had 50 of each on the same tracks.

MR. RIES:—I should like to have Mr. Boynton inform us if he will, as to the frequency of the train service on the particular line which he refers to, and of which he has charge. That is to say, how many trains are actually driven from the generating station at the same time, whether there is any lull worth speaking of between them, or whether the schedule is so arranged that the generating station has a practically constant load upon it at all times. That would throw some considerable light on the subject of the advantage on the line in question, of the train unit operations, that is, as to the relative merits of individual small units or long train units.

MR. BOYNTON:—I would state that I have a general supervision of several lines, and they are all different. The heaviest one, and the one that carries the most passengers, is perhaps more referred to than others. The train service on that line is half hourly, and to reduce it to the basis of the paper it means a half-hour train from each end of a 10-mile run passing in the middle. But there are other portions of the road dependent upon the same power station, so that in the summer, with the electric heaters off, the load will vary perhaps from 200 amperes, which practically means one train, to 800, which practically means four trains, and of course the starting of that number of trains will run this up considerably higher for a few moments. Mr. Pope and others have mentioned the subject of ice on the rail, and it is with us a most important subject, and I think to almost all railroads using this kind of a rail. Ordinary sleet, the shoes and stiff wire brushes will scrape off; there is no doubt about that. But there is a kind of sleet which I tried to describe in the paper (perhaps I did not succeed), which we will call a coat of varnish, and you cannot get it off with an ax. You can chop it, and do anything you please to it, and it sticks like a brother. Nothing will move it, apparently, until the temperature changes and it loosens up, and if I am not mistaken, some of our elevated roads this winter have been tied up more than once from that very cause. Take that kind of ice and strike it with a knife or an ax, and you make a slot across it, which shows just where the edge struck it. Strike it in half a dozen other places, and you make half a dozen marks, and the sleet between the marks is stuck just as tight as it was before, and that is the kind of sleet which is hard to remove. Sleet that you can strike a blow, and it will fly off, gives no trouble. Upon such questions as this depends the successful operation of the road, and when the weather or some other unforseen circumstance ties up the road for a few hours, it is rather humiliating, to say the least.

I have recently been experimenting on methods of removing sleet from the track, using various substances upon the contact surface of the rail to prevent the ice from sticking to it, no matter what the temperature is. I have seen the railroad freeze up in five minutes when it was raining. I have seen a car go through and the next car behind it was stopped. I have recently tried a piece of tool steel consisting of a plate three-quarters of an inch thick and perhaps ten inches square, sliding in grooves, controlled by a lever, by which you can push the plate down on the top of the rail in a vertical position. As far as we have tested such a thing it takes everything off the rail, almost including a chip off the steel rail, and it keeps itself sharp, so that it looks as if the problem was pretty nearly solved; but there are certain matters that have to be perfected, for instance, it is almost absolutely necessary to slide the plate vertically, just as near the vertical as you dare, and then it will cut and will keep itself sharp, but if it is back of the vertical it loses a good deal of its cutting power, and it must also be so arranged that when it strikes a joint or a break in the rail, it can back off and jump over and come forward again, which can be done by means of powerful springs. Those little points seem unimportant, but they are vital in running a road, and I am not aware that they have been solved yet.

[Adjourned.]

DISCUSSION AT CHICAGO, FEBRUARY 28, 1900.

MR. BION J. ARNOLD:—We recognize in Mr. Boynton's paper a careful analysis of the relative advantages of steam and electric traction, and a concise digest of the present practice in constant potential direct current railway work. Inasmuch as the paper gives the results of Mr. Boynton's experience on a heavy direct current line, it is of special interest and benefit to electrical engineers, and should be to railway officials contemplating the equipment of their lines electrically.

However, owing to the present state of transition, being as we are, between the direct current road and the alternating current road, it is hardly safe for any one to take a positive stand and assume that we are going to confine ourselves in the future to a direct current road. Mr. Boynton's paper seems to point out many difficulties for which he is seeking solutions, that would not be present in case the alternating system were adopted. I refer especially to rail bonding; to the question of working conductors, and the feeder system. It is possible that in the near future we shall see the direct current largely abandoned for new construction, and our long distance roads operating with alternating motors, probably at much higher voltages than at present seem practicable. In fact, it seems essential to increase the trolley voltage, if we are going to handle the heavy trains mentioned by Mr. Boynton, at high average speeds. When we consider that in order to make an average speed of 45 miles an hour with a train weighing 100 tons, stopping an average of once every three miles, it requires a maximum capacity of 1600-horse power on each train, it will readily be seen that the amount of current at 700 volts becomes greater than can be carried by any reasonable amount of copper, and by any known means of contact shoes or trolley wheels. This also applies to the bonding of the rails. For this reason the only practicable way is to increase the voltage of the working conductors, thus cutting down the current, and the cost of transmission lines.

Regarding the cars, it occurs to me that the most probable solution will be the adoption of heavy cars for through traffic, equipped with motors designed especially for long runs and few stops, and lighter cars for the local or feeder service; this being practically the style of equipment that is adopted by steam railroads for similar work. Each car would be a motor car in itself. If the heavy train should ever be used for high average speed, and numerous stops, it seems necessary to equip each axle of each car with motors, for the reason that it is impossible to get sufficient adhesion to accelerate the train rapidly from but two pairs of traction wheels on each car.

MR. R. H. PIERCE:—I agree with Mr. Arnold that this paper is most interesting as showing the present state of the art; but it seems extremely doubtful if it will enable us to draw any general conclusions as to what will be done in the near future in electrical railroading.

In figuring over a number of propositions where it has been proposed to use electricity for heavy trains at a high rate of speed, I have always been forced to the conclusion that it was economical to resort to polyphase transmission for distances considerably less than 10 or 12 miles. I believe in most cases we will reach the limit at about one half that distance. The distance at which you can transmit with direct current in many cases is shortened up by grades which call for heavy current, in cases like those mentioned by Mr. Boynton, or even those mentioned by Mr. Arnold. Of course in each special case the distance at which it is economical to transmit with a direct current depends upon the grades, and also upon the cost of producing power in that locality.

Although it is true as Mr. Boynton says that up to the present time it has been impossible to operate trains with alternating current motors, it seems as if the possibility of a solution of this problem in the near future ought to be considered in designing an electric road of this kind; and I am inclined to believe that the equipment of a road to-day with polyphase generators of low frequency may be considered a conservative step in view of the possible, and not improbable, developments of the alternating current motor in the near future. Of course such a system at present would mean the use of sub-stations with rotary transformers, as referred to by Mr. Boynton.

Inasmuch as I stand in Mr. Boynton's place here this evening it is hardly becoming in me to criticise any of his statements, but it would seem as if there might be a difference of opinion on some of his conclusions as to the best methods of obtaining certain results. In speaking of the matter of feeders, he comes to the conclusion that steel is cheaper and more satisfactory. I doubt if experience has shown this to be so. Where steel has been used for feeders in the past, second-hand rails have frequently been used, and when you consider the difficulty of bonding these, as fully explained by Mr. Boynton, it is evident that these rail circuits have been very poor conductors. There seems to be a great scarcity of data on this subject. I note that one of the leading authorities assumes that a steel rail will have a conductivity of one-sixth that of copper, of equal weight; and this figure has often been taken for granted by railroad men. I note, however, that in a paper which was read not long ago before the Institution of Electrical Engineers of Great Britain the figures showed that the conductivity of steel was in many cases, only one-tenth or one-twelfth that of copper. When the resistance of the bond is taken into consideration and the cost of bonding, which Mr. Boynton says is $2 a joint for heavy bonding, I think it probable that many of the steel circuits which have been put up, have proven more expensive than copper would have been. At the present market price it seems that aluminium is cheaper than copper, and probably cheaper than steel.

In regard to the electric lighting of stations, it seems to me that an enterprising electric light company could furnish a satisfactory light cheaper than the railroad company could do it by the method shown here. This method contemplates the use of 120 volts for lighting, and the throwing away of the difference between that and about 700 volts in resistance, which would make an efficiency of only about 20 per cent., discarding the loss in the battery, and at the same time calling for an investment of $900 on a 60-light plant which would be an investment of about $300 per kilowatt. There are other successful ways of producing cheap lights at present.

This reminds me of one case where a station agent very carefully figured out how much he could save over the use of gas by purchasing electric light from a local company. He sent his report in to headquarters, and was informed that after figuring it over they had come to the conclusion that he could save still more by burning kerosene, and therefore he should discontinue the use of gas.

MR. GEO. M. MAYER :—I move a vote of thanks to Mr. Boynton for his very able, instructive and interesting paper.

Motion carried unanimously, and the meeting adjourned.

[COMMUNICATED AFTER ADJOURNMENT BY M. H. GERRY, JR.]

The paper of Mr. E. C. Boynton contains much interesting information, and is a valuable addition to the literature of this subject. Its title, however, suggests to the writer the pertinent question, which has often occurred to him in considering electric traction problems, whether it is well to follow too closely the precedents established by practice in railroading under the present steam *locomotive* conditions. Certainly, practice long established and demonstrated as correct, should not be lightly cast aside without good reason, but in this case it is well also to consider the changed conditions which electric power introduces.

Modern railroading is the result of a vast amount of practical experience in adapting *direct steam power* to the economical transportation of freight and passengers. It is both interesting and instructive, however, to remember that the early attempts at steam locomotion were in the line of traction engines, and were directed to adapting the new motive power to common roads and wagon conditions. Even after steam was applied to the early tramways, we can trace from the old prints the natural attempt to adapt the stage coach to the new order of things.

Everyone is familiar with the later metamorphose of the street railway. We have seen the small horse car, without trucks, and running on light flat rails, pass away, and its place taken by the modern electric car on the heavy track construction of to-day. The new motive power made possible a desirable change in operating conditions in the direction of better and more efficient service, and this in turn, has had its effect, and has extended the business to its present vast proportions. This development has been due, not to a saving of so much per car mile, but to the greatly increased traffic resulting from the better and faster service.

All this applies to steam railways in a certain degree. The traffic on many lines is becoming congested at times, and there is an ever-increasing demand for faster service both for freight and passengers. The speed of all freight trains and the number of *fast freight* trains in service has increased enormously in late years, and there is an ever growing demand for such service, as railway traffic-men know. To meet these conditions the railroads are adopting very heavy locomotives in order to obtain sufficient power and traction, and have been further forced to reduce the weight of their fast passenger and freight trains. Now, this sacrifices economy, because in operating under *locomotive* conditions the heaviest train is always the cheapest train. Speed, however, is demanded, and it is impossible to obtain locomotives of sufficient power and traction to haul the heavy trains at high speeds. Even if locomotives of vastly greater weight and power could be obtained, and the track and bridges made sufficiently strong to support them, still a point in speed is soon reached when the weight hauled behind the locomotive becomes too small to be profitably handled; that is, the weight of the locomotive and tender becomes abnormally great, compared with the train. It is possible to obtain from steam locomotives, about any practicable speed (seventy or eighty miles are common enough), but the difficulty is to accelerate and haul a train of sufficient weight to make it pay. Here we reach the limit of profitable speed with locomotive power.

The entire weight of engine and tender is of course dead load, and in fast service becomes of great importance. The writer averaged the train weights, the engine and tender weights, and the speeds from the fastest passenger train in service on each of ten representative American roads, and found the average speed at about forty miles per hour, and the locomotive and tender weights about forty per cent. of the weight of the train behind the tender. In special fast mail service, and sometimes in suburban passenger service, the percentage is even greater. The writer called especial attention to this matter of locomotive traction and dead weight in a paper before this INSTITUTE in 1897.*

Another consideration of importance is the accepted fact among railroad men that to successfully handle a large number of trains, it is essential to keep the average speed nearly the same; the greater the number of trains, the more important this

---

*TRANSACTIONS, 1897, vol. xiv., p. 353.

becomes. Hence, of late years there has been a general speeding up of all trains, and this speed problem is one of the most serious which railroad men have to face.

Now, what relation has the above to the question of electric motive power? Just this, that there is a call at the present time for an improved service, and that it is becoming more and more difficult with steam locomotives to keep pace with the ever-increasing demands of railway transportation. Hence, there is a field for electrical motive power, in a direction where it is known to have great advantages.

Electrical traction means centralization of the power generating machinery. The more this centralization takes place, the greater the advantage. Electrical transmission has developed until fifty or sixty miles is an entirely practicable distance for transmitting power. Thus the generating stations may be from one hundred to one hundred and twenty miles apart, and this distance is sufficient for all practical purposes. The chief difficulty is not now in generating or transmitting the power as alternating current, but in its utilization in railway motors. To make use of direct current motors, involves the establishment of rotary-converter sub-stations, and this not only introduces serious complications, but it counteracts to a material extent, the advantages gained by long distance transmission. The first great need at this time, in connection with the introduction of electric power on long railway lines, is the adaptation of the alternating motor to this service. That this can be done the writer has no doubt whatever. The subject has not had the wide consideration which it merits, in view of the possibilities it would open up for the introduction of electric motive power. There seems to be quite a general impression among engineers who have not especially considered the matter, that there is some inherent reason why an alternating current motor cannot be used. Such impressions are erroneous. The induction motor has simply not been especially developed in this line. It is certainly about the best all-around motor for power purposes, and by virtue of its remarkable simplicity and other desirable qualities, it is especially fitted for the heavier and faster railway service. The double conductor required is not a serious objection, except, perhaps, on overhead trolley lines. An induction motor is, in many respects, a much more flexible machine than the ordinary series railway motor, and it can be so designed as to give a better form of speed and torque curve for most kinds of railway service. There are difficulties in the matter of control, but they are relatively less than those which have been more or less successfully met in the case of the series direct current motor. It should be borne in mind that the induction motor has been developed thus far as a stationary motor with special view to obtaining constant speed, high efficiency and high power factor. To adapt the inductive motor to railway purposes, will of course require a considerable amount of development work, but in view of the great benefits to be derived, it would seem to be justified. Whenever the alternating current motor is perfected for railway work, all the other problems in connection with the transmission and distribution of power through the transformers can be quite readily solved.

In regard to the methods of applying the motors to the train, the writer holds to the opinion that for general purposes the *locomotive* construction should be abandoned, and the motors placed on the cars (preferably on every car, but not necessarily so), and controlled from the head of the train. This is both theoretically and practically the best method, and will especially apply to the railway conditions mentioned in the first part of this discussion. Railway motors may yet be as simple as air-brake apparatus. and when this comes there will be a great development in applying electric power to standard railways. It is the alternating current motor that we need now.

If electric power is ever applied largely to standard railways the writer fully believes it will work a revolution in railway methods, and that there will be a decided change in the design of rolling stock. Such great and important changes must come slowly, still the general adoption of electric motors may not be as far off as we suppose at this time.

Helena, Mont., March, 1900.

[Communicated After Adjournment by Carl Kinsley.]

In common with all those who have occasion to compare capacities, I am exceedingly interested in the method proposed by Dr. Pupin. Since the time of Maxwell we have understood that absorption is due to the heterogenous nature of the dielectric, but the measurement of the capacity where we have such a dielectric, as for instance, long cables, is difficult and the results still uncertain. The apparatus exhibited was connected as used by the Gott method of measuring capacity when a direct current is employed. This has been found to be probably the most satisfactory of the many possible methods when there is trouble with absorption and leakage. But instead of using a sine wave such as Dr. Rowland (*Philosophical Magazine*, January, 1898) used with his dynamometer zero power methods, an induction coil is employed which gives a wave rich in overtones. The effect of absorption can be expressed by assuming a resistance in series with the condenser. How largely this depends on the period was shown by Dr. Penniman, (*Philosophical Magazine*, January, 1898, p. 70) who found in one case at a frequency of 14.0 complete periods per second an apparent resistance of 139.6 ohms, while at a frequency of 131.1 the apparent resistance was only 5.2 ohms. The importance therefore of knowing the exact periodicity of the current used and of having a high period is apparent.

When the Gott method of measuring capacity is used, the effect of both absorption and leakage is to increase the apparent capacity. The standard, a mica condenser, has negligibly small absorption. The longer the interval of charge is taken the greater becomes this apparent increase of capacity. This is strikingly shown in the case of the following cable, which is entirely typical. Two rubber insulated wires of the cable were used. Their insulation resistance was high. About one-half mile was unarmored and trenched, while one-half mile, which was armored, was lying in New York harbor. The lowest capacity was obtained by a buzzer and telephone. In the second observation the interval was estimated at one-fourth second, the charging key being merely tapped to close the circuit, while the galvanometer remained connected.

From the shape of the curve it is seen that when the time interval is small it must be determined accurately. With commercial condensers of the beeswax-rosin type, the variation of apparent capacity with time of charge is not so pronounced. Certain ones that are rated at one-third microfarad each show that value after a five seconds charge while after a one-fourth second charge their value is 0.292 M.F. and with a buzzer 0.287 M.F.

For scientific accuracy the electromotive force should be a sine function of known period.

When the capacity of cables and condensers for telegraph service is to be determined, the measurement with an alternating

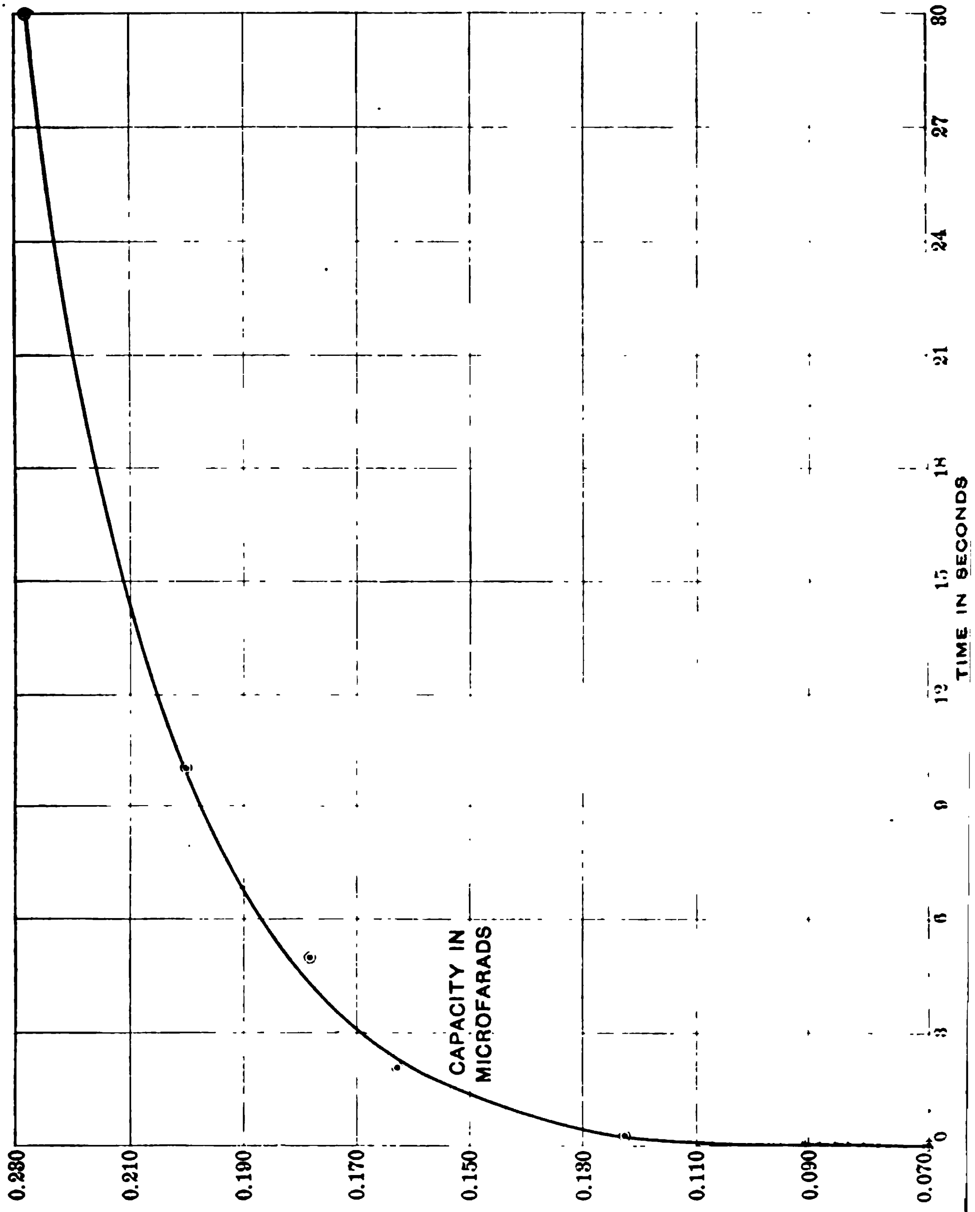


Fig. 8.—Capacity of Cable with Varying Time of Charging.

current will not give the value that must be used in calculations. Uni-directional charging for a suitable time interval will give better values. Possibly there exists a definite relation between the values obtained by alternating, and those usually found with direct current charging. A careful correlation of the various empirical methods heretofore used and the proposed alternating current methods of measuring capacities would be of great value to both the practical engineer and the laboratory experimenter.

The actual capacity changes but little, if at all, with a change of frequency. In commercial condensers (on alternating current circuits) the heating is usually caused by the absorption. Rosa and Swith (*Physical Review*, January, 1899) came to that conclusion though they quoted Boucherot (*L'Eclairage Electrique*, February 12, 1898) who found that the leakage current alone was responsible. In faulty cables it is quite probable that a good deal of energy will be dissipated by the leakage current. This would have the effect of resistance in parallel with the capacity and it will be unaffected by the periodicity of the current. It may be possible to separate the apparent resistance of absorption from the dielectric resistance by varying the frequency. The alternating current method is the only one that can be used when there is bad leakage. With a buzzer, for instance, when even 5000 ohms of non-inductive resistance is bridged across the cable terminals, already mentioned, the capacity rose to 0.075 M.F. instead of the 0.070 found with the high insulation resistance. No direct current method could be used at all under those trying conditions. The great value of the proposed method of determining the capacity is shown by the preceding illustration and it should be made one of the regular methods for making such measurements.

Governor's Island,
N. Y. Harbor, March, 1900.

DIED.

Greene:—At Schenectady, N. Y., January 8th, 1900, by accidental drowning, Samuel Dana Greene, Assistant General Manager of the General Electric Co. Mr. Greene was born in New York City, on October 24th, 1864. Graduated from the U. S. Naval Academy in June, 1883, after a regular four years course, followed by a special course of one year at the U. S. Naval Torpedo Station at Newport, R. I. He resigned from the navy in June, 1887, and went with the Sprague Electric Railway and Motor Co. as Assistant Electrician and subsequently became Chief Engineer. In 1889, he became Assistant General Manager of the United Edison Mfg. Co., and afterwards Manager Central Districts. When the General Electric Co. was organized he was appointed Assistant to 2d Vice-President, and General Manager Sales Department, and subsequently Assistant General Manager. Mr. Greene was elected an Associate Member of the Institute September 20th, 1893, and transferred to full membership April 18th, 1894. In May, 1899, he was elected one of the Managers of the Institute which office he held at the time of his death.

Hamblet :—At his late residence, 20 Sidney Place, Brooklyn, on January 2d, 1900, of pneumonia, James Hamblet, Manager, of the Telegraphic Time Service, Western Union Telegraph Company, New York City. Mr. Hamblet was born in Boston, June 16th, 1824, was engaged by William Bond & Sons as electrician about 1852. He subsequently became a member of the firm of Edmonds and Hamblet, manufacturers of fine mechanism. Since 1878, Mr. Hamblet has been identified with the Western Union Telegraph Company. He was elected an associate member of the Institute November 1st, 1887, and was transferred to full membership December 6th, 1887. In May, 1891, he was elected a Manager of the Institute, continuing until the expiration of his term in 1894, when he was elected a Vice-President for the usual term of two years.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, March 28th, 1900.

The 141st meeting of the INSTITUTE was held this date at 12 West 31st street and was called to order at 8:30 P. M. by Manager Charles P. Steinmetz, who gave the floor to the Secretary to make the usual announcements.

THE SECRETARY:—At the meeting of the Council this afternoon, the following associate members were elected.

Name.	Address.	Endorsed by
BABSON, ARTHUR C.	Student, Electrical Engineering, University of California, Mechanics Building, Berkeley, Cala.	Clarence L. Cory. W. A. Lynn. R. S. Masson.
BARON, MAX D.	Outside Superintendent for Harry Alexander; residence, 61 East 75th St., N. Y. City.	A. S. Hubbard. Fred'k Saxelby. Harry Alexander.
BLACKWELL, FRANCIS O.	Engineer, Power and Mining Dept., General Electric Company, Schenectady, N. Y.	Chas. A. Bradley. Ernst Berg. D. R. Lovejoy.
ESTERLINE, J. WALTER	Instructor, Electrical Department, Purdue University, Lafayette, Ind.	Frederick Bedell. C. P. Matthews. W. E. Goldsborough.
FISH, FRED. ALAN	Assistant in Electrical Engineering, Ohio State University, 229 West 11th Avenue, Columbus, Ohio.	B. F. Thomas. Frederick Bedell. F. C. Caldwell.
FOG, CARL F.	Electrician, General Electric Co.; residence, 29 Commercial St., Lynn, Mass	W. C. Fish. Elihu Thomson. E. E. Boyer.
MACOMBER, IRWIN JOHN	Professor of Electrical Engineering, Armour Institute of Technology; residence, 422 34th Street, Chicago, Ill.	Edw. L. Nichols. H. J. Ryan. Frederick Bedell.
MARSH, HARRY BOWMAN	President, The Advance Electric Co., 8 West Market St., Indianapolis, Ind.	W. E. Godsborough. Harold B. Smith. Ralph W. Pope.

Morehead, John Motley	Engineer, Union Carbide Co., 157 Michigan Ave., Chicago, Ill.	I. R. Edmands. P. M. Lincoln. W. R. Kenan, Jr.
Mortimer, James D.	Student, Electrical Engineering, University of California, Mechanics' Building, Berkeley, Cala.	Clarence L. Cory. Wm. A. Lynn. R. S. Masson.
Offinger, Martin Henry	Head of Electro-Mechanical Dept., Buffalo Commercial & Electro Mechanical Institute; residence, 304 Pine St., Buffalo, N. Y.	Edw. L. Nichols. H. J. Ryan. Frederick Bedell.
Rushmore, Samuel W.	Proprietor, Rushmore Dynamo Works, 24 Morris St., Jersey City, N. J.	M. J. Wightman. J. E. Woodbridge. Joseph Wetzler.
Shaw, Aubrey Norman	Draughtsman, A. B. See Mfg. Co.; residence, 298 Carlton Ave., Brooklyn, N. Y.	A. B. See. Samuel Sheldon. A. Treadwell, Jr.
Stutz, Chas. C.	Chief Draughtsman, Sprague Electric Co.; residence, 58 West 71st Street, New York City.	George Hill. F. A. Scheffler. Geo. B. Damon.

Total, 14.

And the following associate member was transferred to full membership.

Frank W. Brady	Professor of Engineering and Physics, New Mexico College of Agriculture and Mechanic Arts, Mesilla Park, N. M.

The returns from the nominations were canvassed this afternoon by the Council and the following nominees were selected.

For President:—Carl Hering.

For Vice-Presidents:—Gano S. Dunn, Arthur V. Abbott, W. L. R. Emmet.

For Managers:—W. S. Barstow, Calvin W. Rice, Cary T. Hutchinson, Ralph D. Mershon.

For Secretary:—Ralph W. Pope.

For Treasurer:—George A. Hamilton.

The Chairman:—The next business in order is the reading of a paper by Mr. Joseph Sachs on "The Evolution of Safe and Accurate Fuse Protective Devices." I give the floor to Mr. Sachs.

A paper presented at the 141st Meeting of the American Institute of Electrical Engineers, New York, March 28th, 1900. Manager Steinmetz in the Chair.

THE EVOLUTION OF SAFE AND ACCURATE FUSE PROTECTIVE DEVICES.

BY JOSEPH SACHS.

PRESENT STATUS OF FUSES.

So much has been said and written of the shortcomings of the so-called safety fuse, that another discussion in this direction would certainly be but the raising of an old and well known ghost. Aside from voluminous other literature, the TRANSACTIONS of this INSTITUTE record an ample array of investigations, tending to show the unreliable and far from satisfactory behavior of fuse metals, as commonly used under various conditions, and in many instances, indicating directions in which the action of such appliances may be greatly improved. Material improvement has been made in the blocks and bases for receiving these electro-thermal safety valves, but improvement in this direction partakes very much of the character of a quarantine instead of a prevention or cure for the disease. Notwithstanding the refinements and precautions adopted in the installation and use of these essential appliances, they are considered more a necessary evil than a safe and accurate protective device, whose addition to any electrical service would eliminate instead of, as in many instances add another danger element. In view therefore, of the universally poor reputation of fuse cut-out appliances and their failure to satisfactorily perform the service for which they are intended, the materialization of the promise held forth in the title of this paper may warrant a re-discussion of the fuse problem, with particular reference to the conditions and principles on which this much desired device is based and operates.

With the object of producing a protective device which could lay claim to safety and accuracy in fact and not in name only, the writer began a series of experiments several years ago. As a result of these experiments, a new form of fuse protective device has been developed which from extensive tests and various kinds of actual service has shown itself safe and accurate. This device is of the so-called enclosed fuse type which in several perfected forms has recently attained particular prominence, and which promises to be the cure-all of fuse difficulties.

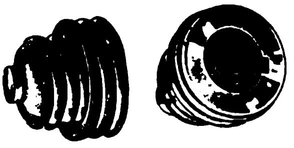


Fig. 1.—Edison Fuse Plug.

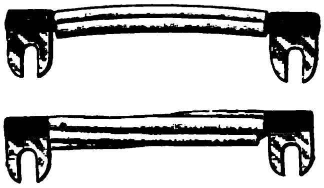


Fig. 3.—Soft Rubber Tube Fuses.

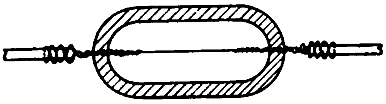


Fig. 2.—Edison Enclosed Fuse. Patent of May 4, 1880.

Fig. 4.—Fuse in Center of Close Fitting Insulating Cylinder.

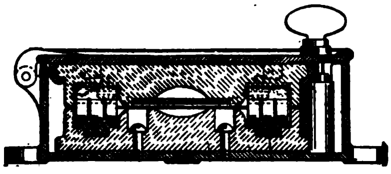


Fig. 5.—Fuse encased between two Insulating Blocks.

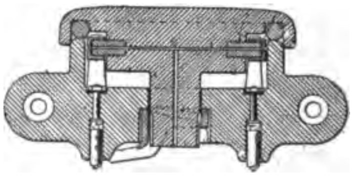


Fig. 6—Fuse in Centrally Vented Holder.

Broadly speaking, the name "enclosed fuse" may be applied to any fuse-strip, covered encased or surrounded by a jacket, box or shell of some kind. Considered thus, probably the earliest device used in common practice fulfilling these conditions is the now famous Edison fuse plug, Fig. 1, whose tremendous success is unquestionably due to the facility with which it can be manipulated and the partial protection of the surroundings from the resulting effects of fuse disruption.

The value of such encasing of the fuse was fully appreciated even earlier than this, as is shown by a patent to Edison, Fig. 2, in 1880, which may be considered as the beginning of enclosed fuses. Fuses surrounded by abestos wrappings, close-fitting rubber tubes, threaded through and placed between blocks of insulating material, and placed in two-part blocks which formed practically a casing around the wire have followed. [See Figs. 3, 4, and 5]. For use on high potentials, a variety of fuse cut-outs have been used in which the fuse wire is placed in a hollow handle or holder of insulating material and equipped with terminal pieces to which the fuse wire is removably connected, and so constructed that the arc resulting from the blowing of the fuse is more or less destroyed by various mechanical arrangements or blown out by the rush of the air in the handle to the exterior as shown in Fig. 6.

The name " enclosed " or " cartridge fuse " is, however, to-day particularly applied to fuses in which the fusible strip is placed inside of a tubular holding sheath or jacket which is filled with some yielding porous or similar insulating material through which the fuse wire is threaded, and which more or less fills the space between the wire and inside of the tube. The wire, tube and filling are made one complete self-contained device with suitable terminals at its ends. Such jacketed and insulated fuses possess peculiar features. The jacket if properly designed gives to the very deficient fuse the essential accuracy and safety aside from various other desirable additions.

At the present time enclosed or cartridge fuses may be divided into two distinct types, both of which embody the same general elements but differ in their disposition. In both, an enclosing tube entirely encases the fuse and a filling material of the character named, is placed in the tube around the wire. The difference in these two types simply consists in the composition and arrangement of the filling around the fuse. The simplest form is probably that in which the filling entirely surrounds the fuse wire and completely fills the interior of the tube. The other form involves the arrangement of the filling material around the wire so as to leave a portion of the fuse uncovered thereby, and surrounded by an air-chamber usually located about centrally in the tubular casing. Both of these types inherently possess great features of advantage over an exposed fuse wire. Their operation under various conditions of electrical service is, however, generally governed by the same basic, electrical and thermal laws. The features inherent in each have received careful study and investigation, and this paper is intended to discuss the conditions governing the protection of electrical apparatus from excess current, the particular manner in which this new form of fuse protector fulfils these conditions, and the relative advantages of each of the two types.

GENERAL PRINCIPLES OF EXCESS CURRENT PROTECTION.

An abnormal current existing in an electrical appliance tends to cause injury and damage due to heat, sparking, and mechanical and electrical strains and effects, either on the part of the electric apparatus itself or its driving or driven machinery. In the first two, the duration or time interval of the injurious effect enters into the resulting damage or injury as a direct function. The third effect may in some cases cause injurious results in so short a time interval that its action may be said to be almost instantaneous under certain extreme conditions of abnormal current flow.

On all constant E. M. F. systems under normal conditions of operation, an abnormal current is due to a decreased impedance in the combined circuit acted on by the E. M. F. The two extremes of this abnormal condition are termed "overload" and "short-curcuit." In both, the current flow is limited to the condition stated, but in the former the change in the normal condition of the circuit is slight as compared to the latter, when the circuit has been reduced to what may be said to be a minimum impedance. The interval in which these conditions cause injury with a certain normal current carrying capacity in the apparatus or circuit, may be quite an appreciable time in the case of the so-called over-load, or it may be so instantaneous that the time interval is inappreciable in the case of short-circuit, where the current assumes an enormous value with extreme rapidity. Altogether the question of injury from excess current may be simply stated as being dependent upon the abnormal energy impressed on the complete circuit or any particular portion thereof.

All electrical apparatus is intended to, or should carry a normal load current without any injurious effects indefinitely, and it will carry an excess current for a time interval depending inversely on the amount of excess above the normal current before sufficient energy has been transformed to produce injury. Slight momentary rushes, or an excess current of short duration will not cause injury to the apparatus if the total energy developed is within the excess limit of the apparatus. Such changes in the current conditions occur, however, in a very large percentage of electrical apparatus and to open the circuit in these cases every time this occurs without taking cognizance of the time of its existence, is a fallacy unless governed by conditions other than the protection of the electrical apparatus from the abnormal current.

Since, however, the various elements of the complete circuit have a limitation in their current-carrying capacity, a short-circuit must be instantly checked, as such comparatively enormous current rush may apply sufficient energy to many times exceed the instantaneous overload capacity of any particular portion of the combined circuit. In current-producing and converting apparatus, the sudden equivalent mechanical strains in the machine and its connected parts due to this effect are added to the heating strains. Not only is it, therefore, of the utmost importance to limit the maximum value of this enormous rush of current, but after the maximum has been reached and some part of the combined system gives way, an equally instantaneous drop of the current to 0, may under certain conditions cause results, which, although of another character are perhaps equally severe. The instantaneous removal of such excessive loads, taxes the governing appliances of the driving machinery, and also on inductive circuits taxes the insulation, due to the production of excessive potentials resulting from such breaking of the current.

For the protection, therefore, of the electrical apparatus alone without regard to other conditions which may affect its operation, an excess current protective device fulfils every condition if it possesses the following features:

1. A definite, unchangeable maximum continuous running current-carrying capacity.

2. A constant definite energy overload capacity depending inversely on the overload, and adjusted with the allowance of a reasonable safety factor for the apparatus to be protected. In this respect the protective device should be like the apparatus protected, uninjured by a excess of momentary or shorter duration than the time interval causing injury. In other words, it should simply be a device whose factor of safety is less than the device to be protected, but whose operation is based on the same gene-

ral principles. It must, therefore, operate practically instantaneously on short-circuit and in a time interval inversely dependent on the amount of ordinary overload.

3. Its operation should be safe under any condition of abnormal current at the voltage for which it is intended. No device can be universally safe in its self-contained form unless the arc and explosive effect coincident with the rupturing of the circuit under any condition is entirely suppressed. The device should not only prevent damage to extraneous surroundings but should be non-destructive to all connected parts other than those directly operative.

FEATURES OF THERMAL CUT-OUTS IN COMMON USE.

Notwithstanding the many statements to the contrary, no similar electrical device is based on simpler, or even as simple operating principles as the thermal cut-out, as it may properly be called. The generation of heat in any current-carrying conductor is a well understood phenomenon. The rise of temperature in this conductor, due to the heat energy imparted to it, is governed by well-known conditions. If these conditions could be made fixed instead of constantly varying quantities, accuracy and certainty of action would result.

The heat energy imparted to a section of conductor by a certain current flowing for a definite time is a fixed quantity. The temperature attained in this conductor depends simply on how much of this heat energy is thrown from the conductor during that particular time interval. It is entirely obvious even without the various experimental investigations on this point, that any condition that varies the amount of heat energy taken from the conductor, varies the temperature attained, and hence the carrying-capacity of the conductor, since the melting of the metal is dependent thereon. The several ways in which this heat is dissipated from the ordinary air-exposed fuse conductor is entirely familiar to all electrical engineers but fuses always have been, and, are now, and in the case of open air fuses, probably always will be used indiscriminately without regard to these simple facts, and yet constancy and accuracy are expected.

Perhaps even more serious, however, than accuracy is the lack of safety in the ordinary exposed fuse. On this score a multitude of transgressions are heaped up against fuse devices of such types as have been in use a dozen years on nearly all classes of high and low voltage services. No exposed fuse is safe (considered from the standpoint of fire hazard to its surroundings). The destructive and dangerous arcing of all exposed fuses when ruptured by excess current and particularly short-circuit conditions at the higher potential must be entirely and not partially eliminated before the fusible cut-out can be considered a perfectly satisfactory protective device. Even when a fire-proof housing is provided, safety is not absolutely assured. This serious objection to all open fuses is becoming more, rather than less serious in its aspects in view of the introduction of higher potentials and enormous generating capacities.

Aside from the shortcoming already stated, air surrounded fuses have other failings, prominently amongst which is the oxidation of the metal when subjected to heat, to which probably as much of the unreliability of such fuses may be attributed as to the conditions already stated. The formation of an enclosing envelope of oxide around the commonly used lead-tin alloy fuse wire is in many instances sufficient to hold the metal in a molten condition. The effect of such a condition is entirely obvious and well appreciated. The ease with which the cross-section of exposed fuses may be decreased by accident or otherwise ; the position of the fuse, whether vertical or horizontal, the straight or irregular arrangement of the strip between its terminals, and the contact between the fuse and circuit contacts: all have their effects on the carrying capacity and are deficiencies well understood and thoroughly appreciated. It is true that the use of a strip of fuse wire between terminals of better conducting metal would partially eliminate some of these bad features if an absolutely standard length between contact posts or screws were assured, but the loose practice of the past did not indicate any appreciation of the fact that any piece of porcelain having several brass stampings or castings mounted upon it is not necessarily a safe and accurate mounting for the simple yet delicate device whose exactness of operation can only be arrived at by definitely fixing all the conditions upon which its action depends.

Aside from the inherent deficiences of open fuse wires and links, the makers of such appliances are very much to blame for an absolutely loose and slipshod method of rating fuse wires and strips. The following matter is copied from three labels taken from spools of commercial fuse wire of different manufacturers. Such labels vary in indefiniteness from simply an omission of the time of fusion to an omission of everything except so many amperes with the appended guarantee. It would certainly appear that this particular rating would be equally definite if the label simply informed the buyer that the wire he purchased was fuse wire. It certainly would have required less trouble in getting up the label and no more for the purchaser to discover whether 25 amperes was the blowing current, the maximum indefinite carrying capacity of the wire, or some other current that the wire would carry, and in what length and under what conditions it would carry this current. Lamps sold without any statement as to the voltage for which they are intended, almost corresponds to selling fuse wire by simply stating some current that it may or may not carry.

A.

Carrying Capacity, 10 Amperes.

Fusing point in open air at 70° 2 inch piece attached to Copper Terminals, 19 Amperes.

B.

Diam. .127

This rating is based on fuse wires 1′ long with copper tips. Amperes 75.

C.

25 Amp.

Tested Fuse Wire Warranted.

There is no reason why this condition should have existed. Fuse wire can be rated as any other electrical device is rated at its maximum indefinite carrying capacity, although it may have been difficult to guarantee its use under conditions of rating.

Since the temperature attained in a conductor depends on the rate at which heat is received and thrown off, the fuse is essentially a time-interval device whose operation is based on the same principles that govern the injurious effect of the current on all other electrical apparatus.

Possessing inherently extreme structural simplicity, and involving an operative principle, not only due to the amount of current but also the time of its duration, the fusible cut-out need only have added to it, elements that will standardize the varying conditions which now beset it in service, and effectively eliminate the injurious arcing. Not only can these desirable features be attained in the manner already mentioned, but by a proper selection of fuse metal and its environments, such devices can be constructed to entirely fulfil the three conditions given.

General Features and Description of Enclosed Fuses.

If the length of the fusible conductor is definitely fixed, the terminals properly proportioned so that the heat conduction from the fuse through them is correctly adjusted, and the fuse then protected from moving air currents and placed in an environment which cannot affect its action as to fusing, and which has a definite capacity for heat reception from the fusible strip, then some of the variable factors affecting the reliable action of the fusible conductor become fixed, and the rise of temperature in the fusible strip for a certain current can be quite definitely relied upon.

Perhaps the very simplest arrangement embodying these elements compromises a definite length of insulating tubing entirely enclosing a fusible wire which is centrally fixed therein and surrounded throughout its length by the tube enclosed air as shown in Fig. 7. Such an arrangement fixes the length, terminals and environment, but it still gives us only an air surrounded wire with the disadvantages of air surrounded fuse wire and by no means produces a device which will operate on severe conditions of abnormal current flow without serious explosive effect. It is true that such fuses in very small ampere capacities, inside of two or three amperes, and at low voltages can be made to work successfully without explosion, but even then the tube must be strong if it is desired to withstand severe short-circuit without disagreeable external manifestations.

A casing might be constructed of sufficient strength, to withstand the pressure of the interior explosion and by a slight leakage arrangement allow the confined gases to gradually escape, but the practical limitation would soon be reached with fairly large current capacities at moderate or high service voltages. Various tests have amply demonstrated this.

By a very simple addition shown in Fig. 8 we can greatly improve the operation of the device as far as explosion and bursting of the tube is concerned. If the tube is entirely filled with some finely divided insulating material such as powdered chalk, the heat due to disruption of the fuse wire, instead of giving rise to an abnormal pressure in the enclosing tube by the heating and expansion of the enclosed air, will be largely taken up by the filling. The small remaining volume of air in expanding passes through the interstices of the filling and parts with more or less of its heat that would otherwise give rise to a destructive pressure. Larger capacity fuses will require firmly held end closures and vents somewhere in the enclosing shell, so that gases may escape from the tube. While the arcing of the enclosed fuse has been cured, the results due to the holding of the metal in a molten condition by the oxide film have been aggravated instead of relieved. The firmly packed filling around the wire serves as a secure bed for the melted metal and its oxide film, relieving it of all supporting strain and maintaining it in continuity although entirely in a melted condition.

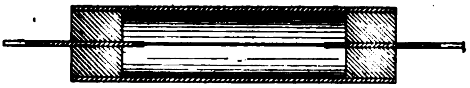


FIG. 7.—Air Filled Tube Fuse.

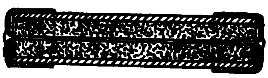


FIG. 8.—Chalk Filled Solid Packed Fuse.

The writer has made extensive experiments with this exact combination and amply demonstrated this seriously defective action. Fuses so constructed with lead-tin alloy and other wires would only disrupt the circuit when the wires attained a temperature apparently sufficient or almost so, to cause volatilization, heating the environment in some instances to a temperature which caused a burning and carbonization of the ordinary vulcanized fibre-tube which was used. This condition is maintained as long as the complete fuse is kept absolutely at rest, for any vibration, shaking or sudden movement of the fuse and block causes a disturbance of the fluid but firmly held wire and consequently a complete rupture or a decrease in its section at some point and consequent rupture at the current which it carried. The effect of a horizontal or vertical position of the fuse was examined, but it was found that the fuse would hold in a melted condition even when placed vertically, if the filling was firmly placed around it. This action is due not so much to the firmly packed filling as it is to the strengthening of the oxide film by this closely surrounding material. As an example of actual operation the following record of a test made of a commercial fuse of this type is given.

RECORD OF TEST OF X SOLID-PACKED FUSE.

GENERAL DESCRIPTION OF FUSE.

Grey fibre tube dia. ½", length 2-½" including brass ferrule caps at ends which served as contacts and to which tin-lead alloy fuse wire was directly soldered, extending from ferrule to ferrule centrally through a filling of white powder of chalky appearance and character. Fuse marked 6 and intended for 220-volt service. Not knowing what this rating was intended to imply, the fuse was started at 4 amperes and current increased.

4 Amperes	for 5 minutes	Block in which fuse was supported well shaken after each interval. Tube hot.
5 "	" 5 "	
6 "	" 20 "	
7 "	" 15 "	At end of this time block given two quick raps and fuse opened. Tube abnormally hot.

For all but short-circuit working, fuses so constructed are therefore defective since no accuracy of rating and blowing can be attained.

With the two above constructions well-known, the next step toward the production of a properly operative device is accomplished by simply effecting a combination between the air-filled tube and the tube filled with finely divided insulating material and by placing the fuse wire in the manner already described. As will be obvious from the illustration, this type of enclosed fuse obtains the advantages gained by a filling material around the fuse wire and also the advantages of a fuse suspended in an enclosed chamber of still air, a fixed environment, standard length and self-contained construction. It is, however, also true that the fuse-strip is affected by oxidation as any similar strip would be if surrounded by air. If such oxide coating should form and tend to affect the wire as already described, its action would be aided by the very short air space in some of these fuses and correspondingly short wire suspension. The rupture of the fuse strip under conditions of overload and short-circuit is initially similar to a rupture of a similar fuse entirely exposed in air. The heated and expanded air, enclosed in the air chamber and the gases resulting from the disrupted wire are forced into the interstices of the porous filling on each side of the air space and pass out, the arc being destroyed by the rush of all air to the exterior without any re-supply, and thus partially blowing out the arc and partially killing it by its inability to maintain itself in an entirely carbonic oxide gas environment. Two designs based on these lines have thus far been commercially developed in this country, and a similar construction has been exploited in England. Sectional views of the two American designs are shown in Figs. 9, 10, and 11, These drawings are self-explanatory.

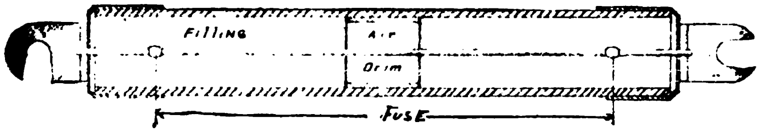


Fig. 9.—Central Air Space and Loose Finely Divided End Filling Fuse (Single Wire).

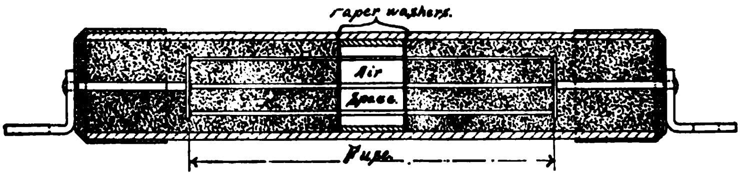


Fig. 10.—Central Air Space Fuse. Multiple Wires and Loose Finely Divided End Filling.

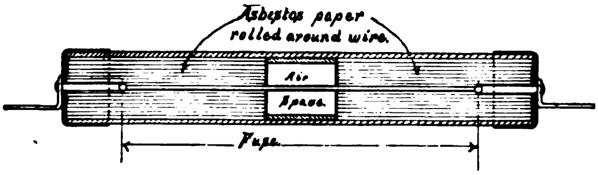
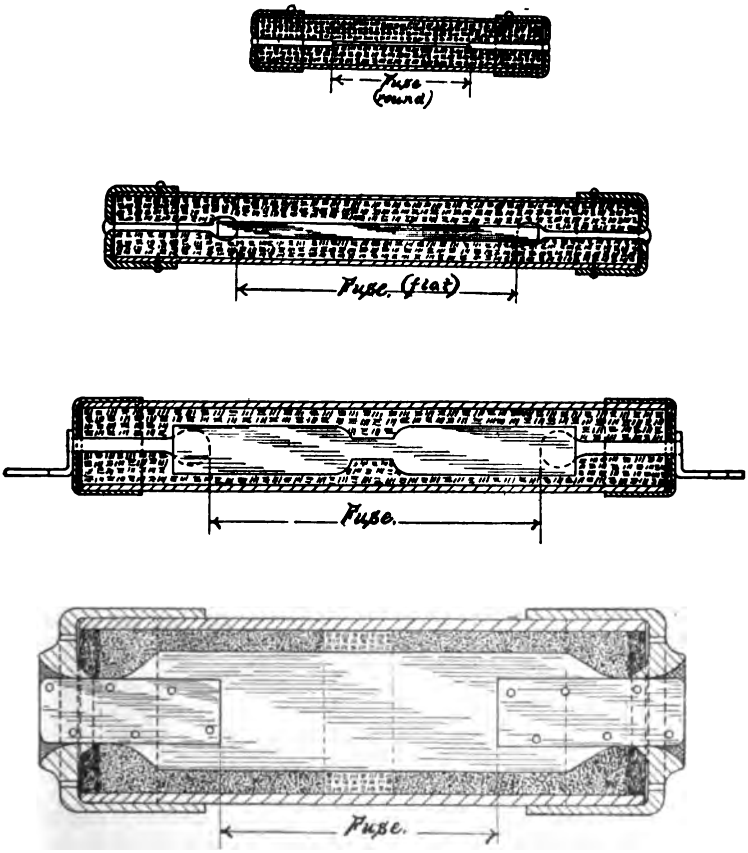


Fig. 11.—Air Space and Asbestos Plugged Fuse.

The design shown in Figs. 9 and 10 has unquestionably accomplished most excellent results in a very large number of installations and in various current capacities and even at very high voltages. The modifications in the fuse strip construction showing the use of single and multiple wires between the terminals is to be noted. By the use of such multiple wires a smaller aggregate area of metal is necessary than when one single wire is used. It may generally be stated that the operation of this type may be varied by a variation in air space length and area aside from other conditions which will be more fully discussed later.

Owing to the absence of vents in the end caps and the slight porosity of the tube filling material in Fig. 11, which is abestos paper rolled around the fuse wire instead of a loose finely divided powder material as used in Figs. 9 and 10, the former design judged from tests made by the writer appears to be of doubtful utility under very severe conditions and particularly if in very large sizes.



FIGS. 12, 13, 14, 15.—Solid Packed Fuses.

The writer's original conception of a non-arcing accurate fuse was to combine with the fusible strip an environment suitably held around the wire and intended to effect a combining action between the wire and heated fuse metal, so that not only would the holding in a molten condition be overcome, but the combining of the environment with the oxides of the disrupted fuse would kill the arc. This principle has been the basis of development in the investigations taken up in this direction by the writer. The results as at present perfected show a fuse protector whose general construction is of the solid packed no-air-chamber type, but in which a molten hanging of the wire is impossible, and in which the explosive tendency is reduced to a minimum, and all flashing and arcing entirely eliminated. This fuse is furnished with an indicating device on the exterior of the casing which at all times positively shows the condition of the interior wire and the rupturing of the fuse wire is of a character peculiarly its own. Figs. 12, 13, 14, and 15 show modifications of the interior construction of this fuse. From the experimental investigations leading to the production of this device, various deductions relative to the proper design of such protective devices have resulted, many of which are equally applicable to all fuses. A discussion of these is combined with the following description of the various elements entering into the construction of this protective applicance.

Operative Principles of Enclosed Fuses.

The satisfactory operation of an enclosed fuse is based on a careful consideration of the following:

1. The character, size and form of the fusible strip.
2. Length of active fusible strip.
3. The character and mass of the fuse environment.
4. The interior section and length of the enclosing casing.

To these may also be added the necessity for indication, compact size and facility of manipulation and low cost.

The character of the metal employed is of the greatest importance, since the heated gases and pressures consequent upon the disruption of the fuse in the casing, and the tendency to arc and explode, is governed by the mass of metal to be disrupted at any particular current condition and voltage, and the conducting nature of its vapors. A metal of high conductivity, whose vapors rapidly and readily change their conducting nature, and which has a fairly high melting temperature, fulfils this requirement. In the matter of conductivity, there is no limit, but the character of the wire environment restricts the raising of the temperature to a point beyond which the casing is injured, and which may be objectionable from other causes. A metal having the current conducting properties of copper would constitute an ideal fuse metal for enclosed fuses. Copper wire, however, is not desirable, in view of the temperature limitation, and the fact that this metal when disrupted results in a vapor which seems to be of the most highly conducting nature, feeding the arc and causing it to hold and burn back on the terminals with a tenacity exceeding that resulting from almost any other metal which the writer has experimented with. This peculiarity of copper vapor is amply demonstrated by the deposition of a film of metallic copper on the ordinary types of fuse blocks, due to the arc attacking the copper terminals of the fuse links. Experience with various metal alloys containing copper seems to give similar results. On 500-volt D. C. circuits, under severe conditions of short-circuit, with fairly large exposed copper fuse wire, the roaring, holding and flashing of the arc is certainly sufficient to prohibit the use of open copper fuses where such abnormal current conditions are possible on these higher voltage circuits.

The commonly used lead-tin alloy fuse metals by no means possess the desired characteristics. It is true that fuses composed of such metals do not, on disruption, give rise to as highly conducting vapors, as copper; but owing to their comparatively poor conductivity and low melting point, they essentially must embody a large mass of metal in any fuse of given length, due to the ample section required. The severe oxidation of such fuse alloys and the possible change in molecular structure of alloys of this type subjected to repeated heating and cooling must not be overlooked.

The search for a satisfactory fuse metal seems now to be directed toward such metals as aluminium, cadmium, tin, zinc and those of a similar nature, or their alloys. A simple metal is however, more desirable for this purpose, unless the alloy possesses features which cannot be obtained otherwise. Since the desired metal must be cheap, aluminium and zinc at once become most attractive. Both possess the desired conductivity, and melting point and their vapors have the desired high-resistance property which is, no doubt, due to their extremely rapid oxidation. The mass of metal used in fuse wires of either of these is therefore small, and the opening of the arc is readily accomplished. These two metals have up to date been generally adopted in the writer's various forms of fuse devices, but it is still desired to further advance in the direction noted. Since the carrying capacity of the wire depends upon its ability to throw off more or less of the heat generated therein, it necessarily follows that a single round sectioned wire does not attain the desired goal in regard to the use of a minimum mass of metal. The simplest solution is to flatten the fuse strip and thus raise its heat throwing-off ability to a maximum. Another method is to construct a fuse strip of a multiplicity of wires. The first method is used by the writer in all larger fuses exclusively, and performs another function which greatly adds to the operation of the enclosed fuse and permits the use of smaller tube sections. In order to effect a thorough and rapid commingling of the ruptured wire and filling material, it is essential to bring the maximum metal surface in contact with the filling, which is very well attained by the use of a flat strip.

In fuses intended to work on the various commercial voltages it has been the practice to vary the length of the fuse strip in proportion to the voltage. Owing to the decreased carrying capacity of any particular fuse wire section due to increased length, it is highly advisable to reduce the latter to a minimum, consistent with satisfactory working.

Open or enclosed fuses of ample length when subjected to gradual overloads, in which the temperature rise in the metal is dependent on an appreciable time interval will, if of even section and with an even surrounding environment and similarly connected at each end, attain the maximum temperature at a point central between the ends. The length of the rupture, under such conditions, depends on the ability of the arc started at the initial break in the metallic continuity to consume the metal on each side of the break. With any particular metal this maximum arcing length will depend on the E. M. F. sustaining the arc and its environment. In air this is much longer than in a casing and filling, arranged so as to exclude as much air as possible, and dissipate the conducting vapors of the disrupted fuse metal. For any particular voltage the length of arcing distance obviously depends on the conducting character of the vapors. If, however, the disrupting current is extremely large, as in the case of an enormous overload or short-circuit, then the heating of the complete metal strip is so instantaneous that a melting temperature is attained over its entire length, and it is completely disrupted. An arc will then only result if the distance between the contact terminal pieces on the base block are inside of the arcing distance for that particular metal and voltage.

By an adjustment of fuse-length to meet this condition it is possible to operate an open fuse at any voltage without any arc under short-circuit conditions, but by no means does this in any way affect the resulting arc on slow overload melting of the metal. The length necessary for such non-arcing short-circuit operation will be found excessive in practice. Since the slow overload arcing is retained, and even though disrupted without arc, the short-circuit operation necessarily entails the throwing off of a quantity of molten metal, but very slight additional safety is afforded to the surroundings, although the contacts and other parts of the base block are protected. The enclosing of the fuse wire in a casing properly filled and held around the wire greatly shortens the maximum arcing distance under overload or short-circuit.

The varying severity of short-circuit effects at different parts of the conducting system with large and small generating capacity and with varying conditions of output and character of service, are frequently ignored in considering the operation of protective applicances of this nature. With heavy current capacity protective devices a very small retarding medium greatly affects the operation of the protective device. Short-circuits and heavy overload ruptures, on large over-compounded and low-power factor systems are instances of particularly severe service.

It, is, however, only necessary for a protective device such as a fuse to accomplish satisfactory results on the particular service in connection with which it is used. While it is entirely possible to provide a device capable of meeting the most extreme condition, such ability, if entailing additional cost, is unnecessary where the extreme conditions are impossible. The peculiar result obtained in a recent test made by short-circuiting two of these solid packed fuses on a 2500-volt line and two exactly similar fuses on a 500-volt line, will illustrate the fact that the voltage does not necessarily determine the severity of the short-circuiting effect on a fuse of ample dimensions.

Comparative Short-Circuit Test of Long Fuse on 2500 Volt A. C. and 500 Volt D. C.

18″ long, 1″ diameter fibre tube. Filled solid active powder.

12″ flat fuse strip. Capacity 20 amps. continuously.

A. C. 2500 volts on heavy feeder about 1 mile from station, lightly loaded. Two fuses as above, each thrown singly across line. Opening of fuse tubes after test disclosed about 5 to 5½″ of undestroyed strip in each tube. This remaining length was made up of several pieces. The length of strip destroyed under this condition was from 6½ to 7″

D. C. 500 volts on 0000 feeder about 1¼ miles from station. Owing to load variation, test was made only when voltmeter indicated 500 volts. Two fuses as above. Each thrown singly across line. Openings of tubes disclosed a disruption of the entire fuse strip between terminals with the exception of ½" in one and 1½" in the other.

Similar tests with somewhat longer fuses on 6000 volts show the following results:

SHORT-CIRCUIT TEST OF 5,000 TO 10,000 VOLT FUSES.

S. K. C. Inductor, two phase generator belted to water-wheel. Gates well open. No load on generator except test. Voltage measured 6000. Fuses thrown across short heavy leads connected to one side and allowed to remain connected for some time after operating. Two-phase capacity of generator. 300 K W.

24" long 1" diameter fibre tube. Filled solid active powder.
15" flat fuse strip. Capacity 20 amps.

Two fuses as above tested. Each connected in series with larger capacity fuse and thrown across generator. In both cases the 20 amp. fuse only opened. Opening of tube disclosed a disruption of all except one or two very short pieces of the strip.

The very much shorter disruption on the 2500-volt circuit is noteworthy. It may be due to the inability of the 2500-volt A. C. arc to maintain itself over a greater distance, and also to the lagging of the current rush so that at the instant of rupture the total heat energy acting on the fuse strip was insufficient to totally destroy the entire mass of metal. This experiment is apparently contrary to the generally accepted ideas governing the length and adjustment of fuses of this type. In practice the actual lengths of the fuse strips are very much shorter than those tested on 2500 and 500 volts.

The average lengths as used in these solid packed fuses, are approximately:

220 volts,......	1½"
500 volts,..	3"
2500 volts,...............................	4"
3000 to 10,000 volts,..........	6" to 18"

This is the distance between terminal wires inside and has no particular bearing on the casing, which varies.

The use of inductances in series with large fuses to choke heavy current rushes and thus ease the blow on short-circuit, has been suggested. Recent tests with 600-ampere fuses on a very heavy feeder at a short distance from one of the largest 500-volt direct connected railway stations, has somewhat lowered the writer's opinion of this buffing device. One of these fuses tested without the inductance and thrown directly as a short circuit across the feeders worked in a far superior manner to another having an inductance of about twelve turns in series with it and similarly treated. Indications seemed to warrant the conclusion that while the inductance may have choked the maximum rush; it, however, increased the potential of break across the fuse terminals.

Another important feature dependent upon the length of fuse, its consequent resistance and amount of energy dissipated therein, is the temperature attained by the surface of the tube casing. This depends upon the amount of heat energy delivered from the fuse to the environment and consequently upon the amount of energy dissipated in the fuse for any particular current. A simple arrangement of the strip section, small in the center and increasing toward the terminal wires, accomplishes most excellent results in this direction. Fuses so constructed have a far lower tube surface temperature than when an even strip is employed, although more metal must necessarily be dissipated.

From prior deductions it has appeared that a satisfactory action of the tube-surrounded fuse strip can only be attained by reducing the amount of confined air to a minimum, and by providing a means for effecting a maximum cooling effect on the heated and expanding gases. The closest attainment of this result is obviously in a solid filled tube. Irrespective, however, of the particular quantity of filling in the tube, its presence in contact with the wire, necessarily affects the action of the latter. This environment, no matter what its arrangement, has a certain heat conductivity and capacity. It carries heat away from the conductor more rapidly when cold, than after it and the conductor have obtained a higher temperature. The mass of this material around the wire affects the time required to attain a certain temperature in the wire, and the heat conductivity of the material employed as an environment to the wire will affect its carrying capacity. A proper relationship must, therefore, exist between the wire and the environment, in order that the complete device has a minimum difference in the time necessary to attain an operative temperature in the fuse-strip when first put in circuit, or after it has endured its full current capacity for some time. It is certainly assumed that the filling satisfactorily fulfils its essential function as an arc dissipator, and that the fuse has been properly located therein.

The desired result as to so-called hot and cold blowing of the fuse device is accomplished by reducing the mass of environment to a minimum. It is obvious that with a certain fixed heat throwing-off capacity in the wire, the current carrying capacity of the latter will depend upon the rate of heat conduction to, and dissipation by radiation from the tube surface, and by conduction longitudinally through the terminal wire and environment to the contact posts. The heat conductivity of the environment therefore governs the carrying capacity of the complete device, but this function is decreased if insufficient environment section is provided, so that the radiation and conduction therefrom, owing to lack of tube surface, is not in the proper proportion to the amount of heat thrown off by the conductor. The exterior surface temperature of the tube, other conditions being fixed, is certainly dependent upon the surface area. Decreased surface temperature can therefore be obtained by increased surface area, but this necessarily entails increased mass which is not desirable, for reasons already given. For similar reasons it is desirable to minimize the heat conduction from the fuse to the contacts, through small terminal wires.

FIG. 16.—Strip Ruptured at Low Arcless Voltage in an Environment of Active and Inert Material. Note Rupture at one end of Fuse Strip where Active Material was Located and Melted Condition of Center.

By a careful adjustment of the various parts the writer has obtained comparatively low surface temperature, minimum ratio of hot to cold blowing time and practically very little or no difference in the current carrying capacity of the fuse strip, from that which it has when entirely surrounded by an air environment.

To produce the desired result relative to the prevention of any holding of the wire in a molten condition, a very careful experimental investigation was undertaken. Based on the original conception, a combination of elements has been developed which not only combine under heat action of the current, but in which the character of all or a portion of the environment s such that the retention of the wire continuity after melting temperature has been reached is impossible. This result is accomplished by the use of a material around the wire which readily fluxes with the metallic oxides at the temperature of the molten metal. Various substances are available for this purpose, but the writer has found mixtures in the form of loose, finely divided powders, in which borax is included as an element, most desirable. With the metal employed in the fuse strip, this environment produces most peculiar results, causing a fluxing only upon the attainment of the temperature reached by the wire in its molten overloaded state. This action is clearly illustrated in Fig. 16 showing a photographic reproduction of a strip ruptured at a low arcless voltage. A portion of the strip was surrounded by an inactive environment, while another portion was surrounded by the active powder, an arrangement frequently used. It will be noticed that while a large portion of the strip was reduced to a molten condition, yet only that portion surrounded by the active material fluxed and ruptured. Aside from the material named, the other ingredients of the filling require careful selection.

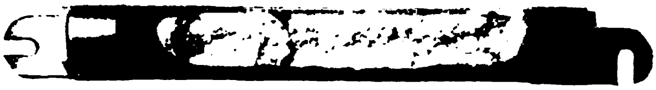


FIG. 17.—Short-Circuit Rupture of 500 V. 50 A. Fuse, Showing Combination.

By the use of such combining material around the fuse strip, other features of advantage are obtained. The combination between the metallic oxides with the environment absorbs the energy of any destructive arc or resulting explosive effect, which may tend to maintain itself under other conditions. The combination of the elements in the manner described is, however, equally as valuable in buffing the break, as a long continued and gradually lengthened arc. The merging together of the metal of the fuse strip and the material of environment necessarily causes a gradual increase in the resistance of the structure between the terminals, which is obviously, in order to make the device operative, a gradation from the practically negligible resistance of the intact wire to the absolute break resulting after a complete combination has been effected, and the metallic strip turned into a non-conducting mass. Fig. 17 shows the interior of a 500-volt, 50-ampere fuse short-circuited at that voltage with the resulting combination. The advantage of this absorption of explosive energy, and the gradual, although rapid letting down of the current, is obvious.

By no means is the mere fact that an enclosed fuse stands the explosive action of interior rupture, sufficient to attest its satisfactory operation under every other condition. After the explosive effect has been subdued or eliminated, the fuse is then subjected to the entire potential of the circuit ruptured. Unless the break is then free from any conducting quality under that particular potential a very slight leak may still be sufficient to result in a heating effect which soon causes afresh a most severe arcing, and the destruction of the entire device. It is for this reason that the condition following a short-circuit, if carried without destruction by the fuse, is sometimes not as serious a test as a gradual slow arcing break, although the instantaneous shock to the fuse is far more severe in the former case than in the latter. If, however, it is considered that a short-circuit will disrupt the maximum length of fuse metal while the slight overload may cause only a very short break, the reason for this condition will at once be seen. Fuses of the enclosed type should, therefore, be tested under both conditions. Those in which the construction and arrangement of the parts is such, that a carbonization or similar formation may result, due to the character of the materials adjacent to the ruptured metal, would seem to be particularly subject to this condition, while those in which the entire wire is surrounded with materials free from these or similar defective properties, would be apt to operate in a far superior manner.

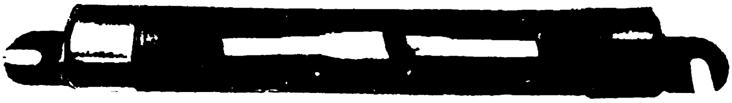


Fig. 18.—Solid Packed Fuse Ruptured by Overload at Low Arcless Voltage. Note Central Location of Rupture.

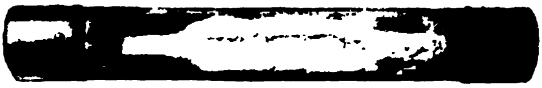


Fig. 19.—Solid Packed 500 V. 50 A. Fuse Ruptured by Overload at Normal Voltage.

Whether or not the complete enclosed fuse will stand severe short-circuit shock also depends to quite an extent on the centering of the wire rupture approximately midway between the ends of the tube, so that its resulting effect may work against sufficient filling material and fusible metal on each side. Fuses in which the connection between the fusible wire and the exterior terminals is made at the end of the tube, are defective unless the ends of the wire or strip are proportioned to act as terminals only, and are therefore of better conductivity than the more centrally located section. Fig. 18 shows a solid packed fuse ruptured by overload at low voltage, and Fig. 19 at normal voltage.

The fact that if properly operative the exterior of the enclosed fuse gives no indication of the condition of the interior wire, is undoubtedly a substantial objection to this type of protective device. Any arrangement for the purposes of exterior indication must necessarily be simple, safe and cheap. The writer has devised several indicating arrangements, and the method adopted, probably meets these requirements. In shunt across the interior fuse is placed a very fine high resistance wire containing a minimum of metal, and placed wholly or partially on the tube exterior with its ends connected to the fuse terminals. The condition of this little indicator wire at all times shows the condition of the interior fuse, since a rupture of the interior fuse at once causes a rupture of the indicator. A peculiar feature, however, in the operation of this auxiliary device, is the fact that on all except the smallest capacity fuses it disrupts practically without any arc whatsoever. The reason for this condition is at once found in the fact that the main fuse is gradually losing its conductivity on rupture, and is at some

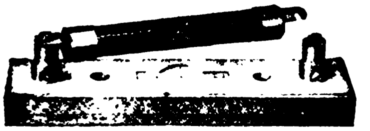


FIG. 20.—2500 Volts, 50 Amperes.

FIG. 21.—220 Volts, 25 Amperes.

particular instant equal in resistance to the indicator. The equally divided current is then sufficient to rupture the indicator, which is still shunted by the increasing resistance of the interior fuse, in which the final break of the circuit really occurs. This fact is amply proven by short-circuiting an indicator wire on a fuse tube with and without an interior fuse in shunt with it. The flash in the latter instance is comparatively severe, while in the first it is entirely negligible.

Fig. 22.—500 V. 400 A. Complete Cutout.

The appearance of some of the solid packed fuses in their completed form is shown in the accompanying Figs. 20, 21, 22, 23. These illustrations, with the various modifications shown in the construction of the terminal fittings, accessory fuse blocks and fittings, are self-explanatory. The general dimensions of these fuses for the different commercial voltages are given in Table A.

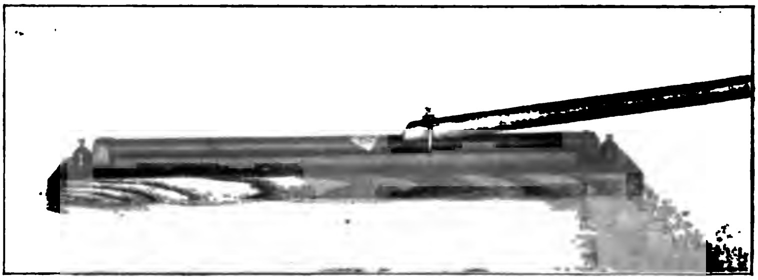


Fig. 23.

TABLE A.

LENGTH AND DIAMETER OF FUSE TUBES.—SOLID PACKED FUSES.

AMPERES.	1 to 8	10 to 15	20 to 30	35 to 50	60 to 100	110 to 150	160 to 200	300 to 400	500 to 600	700 to 800	900 to 1000	1 to 10	15 to 25	35 to 50	60 to 100	110 to 150	160 to 200	300 to 400	500 to 600	700 to 800	1 to 12	15 to 30	35 to 50	60 to 75	80 to 100	1 to 12	15 to 30	35 to 50
Maximum length of fuse tube to outside of caps.	$2\frac{3}{16}$	$2\frac{11}{16}$	$3\frac{3}{16}$	$3\frac{3}{4}$	$4\frac{1}{8}$	$4\frac{1}{8}$	$4\frac{5}{8}$	$4\frac{5}{8}$	$6\frac{3}{8}$	$6\frac{3}{8}$	$7\frac{1}{2}$	$4\frac{5}{8}$	$5\frac{1}{4}$	$5\frac{3}{4}$	$6\frac{1}{4}$	$6\frac{1}{4}$	$6\frac{3}{8}$	$6\frac{5}{8}$	10	10	$5\frac{3}{4}$	$5\frac{3}{4}$	$6\frac{1}{4}$	$6\frac{11}{16}$	7	24	24	24
Diameter of Fuse Tube.	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$\frac{3}{4}$	1	$1\frac{1}{8}$
	220 VOLTS.											500 VOLTS.									2500 VOLTS.					10000 VOLTS.		

HOT OVERLOAD TIME INTERVAL CURVE—25 AMP. FUSES.

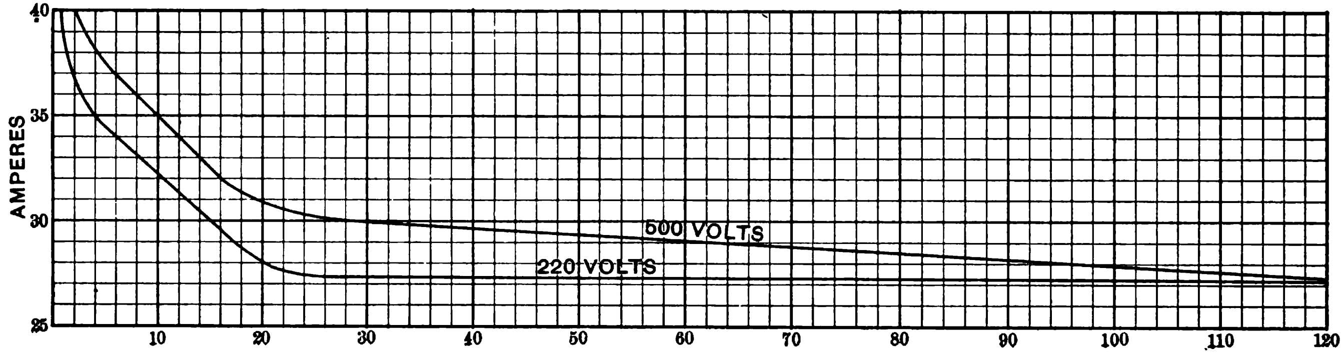


FIG. 24.

THE OPERATION AND USE OF ENCLOSED FUSES.

The desirable time-interval function in properly constructed enclosed fuses gives to this form of fuse protective device a decided advantage, owing to the variation and adjustment of the overload time interval which can be obtained by very simple alterations in the construction. This feature of the device makes it available for almost every class of electrical service. The curves, Fig. 24 show how the solid packed fuses act under varying overload conditions. It will be noted that the time interval increases in an irregular inverse ratio to the percentage of overload. In practice, the arrangement of this time interval function of the fuse is judged by a careful consideration of the particular service for which the fuse is to be used. In standard fuses of the ordinary commercial voltages the following adjustment has been adopted.

220-volts below 20 amperes will carry 25% overload for 10 to 20 seconds.
220-volts above 20 amperes will carry 25% overload for 25 to 40 seconds.
500-volts below 20 amperes will carry 25% overload for 15 to 30 seconds.
500-volts above 20 amperes will carry 25% overload for 30 to 60 seconds.
2500-volts below 10 amperes will carry 25% overload for 10 to 20 seconds.
2500-volts above 10 amperes will carry 25% overload for 30 to 45 seconds.

These overload time intervals may perhaps appear small for certain classes of service, but in arranging and adopting a standard overload time for all fuses of a certain voltage, it was essential that an average time interval be taken, and not one only adopted to some one particular class of service. Special fuses are, however, constructed with any desired time interval.

The rating of these fuses is based on the lines already laid down earlier in this paper, that is: the rating is the current which the fuse will carry indefinitely without rupture. They are, as far as possible, adjusted so that any excess current above this rated capacity will, in time, rupture the fuse strip. But practical manufacture will not permit, nor does practical service demand this condition to hold to more than within five per cent. above this maximum rating.

In the manufacture of these fuses, however, every effort is made to refine each element by a series of tests practically prohibiting variation in the character or quality of materials employed, and finally, after the device has been completed, it is given a maximum carrying capacity test for a sufficient time to guarantee its proper interior construction. The necessity for dimensional and structural accuracy in the fuse strip which increases with the conductivity of the fuse metal employed, has received particular attention. Aside from the very careful micrometer gauging of the strip, each strip is measured for resistance by a rapid drop of potential method.

The writer has been frequently asked whether the carrying capacity of such a fuse under normal conditions is affected by the action of the environment, it being assumed that since the environment co-acted with the metal in forming a combination on rupture, and when the metal was in a molten condition, that this action in a milder form might be present under normal running conditions. It must first be remembered that the environment does not combine with the metal, but with the oxides of the metal, under the action of the heat, and that this combination is only effected when a certain definite temperature or condition of the metal has been reached. The action of such a well-known flux as borax or similar acting material is well understood, and it is known that any action between this material and metallic oxides occur only at a definite temperature permitting of the flowing together of the melted borax and oxides which it dissolves.

In order to determine with exactness whether such condition could exist, fuses have been subjected to their normal current for a long time, and then carefully examined. Other fuses have been subjected to actual service running tests in which the maximum carrying capacity of the fuse was passed through it several hours each day for a period extending over a month or more. In both cases the fuses continued, and are continuing, to carry their rated capacity, and an examination of the strip has shown no attack.

The temperature at which the disrupting action begins, is only reached after the overload current has been on the fuse for the allowed time interval, or within a very close practical approximation of it. The writer has even taken fuses and passed a certain percentage of overload current through them for a time, less than the limit for that particular current, and has afterwards carefully examined the strip without discovering any deterioration therein.

The matter of variation in time interval for any particular amount of overload in the solid packed type of fuse when hot and cold, has been open to quite some discussion.

Table B shows the hot and cold blowing time for a definite overload on several sizes of the writer's fuses as determined from recent tests.

It may appear that this type of fuse has a larger ratio between its hot and cold blowing point for a definite overload than a fuse constructed with an air chamber, as shown in Fig. 9.

TABLE B.

HOT AND COLD OVERLOAD TIME—SOLID PACKED FUSES.

Rating.	Carried.	Time.	Overload	Opened.	Ratio Hot to Cold
500 v. 40 A. flat single fuse	40 a	1 hr.	50 a 50 a	55 sec. 210 sec.	11 to 42
500 v. 25 A. flat single fuse	25 a	1 hr.	30 a 30 a	45 sec. 195 sec.	3 to 13
2500 v. 50 A flat single fuse	50 a	1 hr.	62½ a 62½ a	30 sec. 120 sec.	1 to 4
220 v. 10 A. round single fuse	10 a	1 hr.	12 a 12 a	10 sec. 30 sec.	1 to 3

A few tests of an air space fuse under such conditions indicate that this assumption does not hold good. These are given in Table C., and a comparison with Table B. demonstrates, at least from the sizes tested, that the air chamber fuse of the construction tested, is equally or more subject to this variation than the other type. The reasons for the existence of this condition, whether it be in the one type or the other, have already been discussed. It is to be noted that the air space fuses tested employ a relatively larger bulk of metal and environment.

TABLE C.

HOT AND COLD OVERLOAD TIME—AIR SPACE FUSES.

Rating.	Carried.	Time.	Overload	Opened.	Ratio Hot to cold.
2000 v. 50 A mul. fuse.	50 a	1 hr.	62½ a 62½ a	60 sec. 690 sec.	2 to 23
2000 v. 15 A single fuse.	15 a	1 hr.	18 a 18 a	20 sec. 90 sec.	2 to 9

In order to further test the relative advantages of these two types of fuses, comparative short-circuit tests were made, and the following record of these tests shows the advantage for rapidity of action to again be with this form of solid packed fuse.

COMPARATIVE SHORT-CIRCUIT TEST AIR SPACE AND SOLID PACKED FUSE.

50 A. 500 v. rated capacity of each fuse. Connected in series and thrown across 500 v. Conduit contact rails. Solid packed fuse opened alone. Air space fuse held.

50 A. 2500 v. rated capacity of each fuse Connected in series and thrown across 500 v. feeder at laboratory. Same result as in prior test.

Correctness of "Solid Packed" rating tested before short-circuiting.

Reasons similar to those already stated are potent in effecting this result also. In determining the rating of any enclosed fuse, it is very essential to give it ample time.

Experiments made to determine the carrying capacity of fuse strips such as used in these solid packed fuses when covered with the environment, and when entirely air surrounded and exposed has demonstrated with the several sizes of strips tested, that the current-carrying capacity of the strip is the same, whether it is encased or not. The time interval necessary to bring it up to a definite temperature varies in the two conditions as shown by the test record in Table D. of a 40-ampere 500-volt fuse strip, which may be taken as a fair sample. The smaller fuse strips show a slightly increased capacity when encased.

TABLE D.

RATING TESTS OF 500 VOLT, 40 AMPERES. FUSE STRIPS.

	Tube.	Fuse.	Term'l.	Filling.	Run at	Time.	Checked or References.
Enclosed	¾ x 5¾"	.018 x .13 x 3"	.11 dia.	All active	40 a	1 hr.	
	"	"	"	"	50 a	5< sec	Opened.
					50 a	3½ m.	Opened.
Exposed	None	"	"	Air	40 a	15 m.	
	"	"	"	"	50 a	12 sec	Opened.
					50 a	25 sec.	Opened.

Fuse and terminal wires 5¾ between contacts.

Distance between centers of posts 6¾".

Owing to the fact that the above tests indicated that the uncovered fuse required a far shorter time for its operation than the covered fuse, it is decided to make a comparative short-circuit test of these two arrangements. A record of this test is given below:

COMPARATIVE 500-VOLT SHORT-CIRCUIT TEST OF FLAT STRIPS IN SOLID PACKED CASE AND AIR EXPOSED.

Open and enclosed fuses similar to those used in Table C, rated 40 A. 500 v. enclosed. Flat strip .018 × .18 × 3″ between copper terminal wires .11 diam. 6¼″ between center of contact posts.

Exposed Fuse Strip Alone. **Very severe arcing and burning of terminal wire back to posts. Break 6″.**

Exposed Fuse Strip in Series with Enclosed Strip. **Both fuses opened but exposed strip simply disrupted to terminal wires without any burning and only slight snap. Break 3″ in each exposed fuse.**

It will be noted that instead of being slower than the uncovered fuse, the encased device was equally as rapid, if not more so. This seems to lead to the deduction that on short-circuits the disruption of the strip depends on the instantaneous energy impressed upon it and its specific heat and mass, and the radiation and conduction from the strip to its environment is negligible.

The writer has constructed and operated fuses of the type described, ranging in capacities up to 5000 to 10,000 volts and 30 amperes and 500 volts with 600 amperes continuous running capacity, but is prepared with data already in hand to furnish similar devices up to 1000 amperes on 220 or 500 volts and 50 amperes on 10,000 volts. These fuses are all constructed so as to singly open circuits up to 2500 volts.

It has frequently been suggested that for protection on high potentials a number of lower potential fuses in series might be available. Such an arrangement is, however, defective, owing to the fact that under conditions of short-circuit rush, the shock may be so instantaneous that the disruption of one of these fuses may precede the other. Such condition will frequently act disastrously upon the particular fuse called upon to stand the first blow, which, until shared by another fuse, involves the opening of the total energy of the short-circuit.

On a similar basis the use of several fuses in multiple has been suggested where one fuse having the total aggregate capacity was not available. Such shunting of comparatively low resistance paths necessarily requires the greatest accuracy in adjusting the resistance of each so that division of the current may be equally shared. The impracticability of doing this is obvious, and it is for this reason and others that this arrangement is discouraged, and every attempt made to produce a single self-contained tube, having the carrying capacity desired, and capable of working satisfactorily under all required conditions. The shunting of ordinary circuit-breaking devices by a proper enclosed fuse is an excellent arrangement and permits of most extensive application. All arcing can in this way be eliminated and breaking appliances may then be used at much higher potentials than these for which they are adapted alone.

Aside from the particular constructions noted, which are particularly applicable to fuses for electric lighting, power and similar services, the writer has developed another new type of enclosed fuse for delicate work. In this direction it has been possible to obtain accurate and safe fuses having a rating of .005 of an ampere; and which blow in 15 seconds at .01.

ENCLOSED FUSES *vs.* OTHER PROTECTIVE DEVICES.

A discussion of the relative merits of fuses and electro-magnetic circuit breakers is entirely unnecessary in this paper, since the relative merits of these devices are well understood and appreciated. With a fuse device of the character mentioned available, however, the advantages of the circuit breaker are limited to the applications where a very rapid resetting of the protective device is essential, and where the protective device is desired absolutely without any time factor on overloads. Where such conditions exist it is more frequently a question of adopting a device whose function is to serve as a "circuit-breaker," and which need not necessarily fulfill the ideal requirements of a circuit protector.

It is unquestionably a fact that the perfected forms of both devices have enormous fields, but it cannot be denied that if the device to be protected has a time overload factor, that the ideal method of protecting it is to use in conjunction therewith a time interval protective device. No device has as yet been produced which can perform these functions in a simpler and more efficient fashion than a properly designed enclosed fuse. Aside from this feature, there is unquestionably an enormous field in which the perfected fuse protector is alone.

CONCLUSION.

In describing and discussing the various features of the new device of which this paper particularly treats, the writer does not intend to imply that perfection has been reached, nor that the device in its present condition is capable of meeting every possible condition of unusual service. It is, however, believed that the principles herein discussed are based on good foundations, and that similar devices constructed on these lines can be built, capable of accomplishing results heretofore impossible with the types of fuse and other protective devices in common use. With the introduction of higher potentials in every direction, and the desire to improve the safety factor of electrical service to the utmost, it is believed that the enclosed fuse protector is essentially a necessity, and its entrance into the electrical practice of the present, is undoubtedly but the beginning of a perhaps universal application.

DISCUSSION.

Mr. Sachs:—Through the kindness of our fellow-member, Mr. Lieb, of the Edison Illuminating Company of this city, I am permitted this evening to make a very few tests. They will show the action of the fuse under short-circuit conditions at 220 volts. In order to show you any overload tests it would be necessary to arrange resistances and ammeters and take up more time than is possible under the circumstances. The service, as you have noted here, is a 220-volt service. The various experiments will in a measure substantiate the statements in the paper. [Experiments.]

Mr. Gano S. Dunn:—To start the discussion, I will ask a very simple question. I would like to inquire of Mr. Sachs the relative cost of these fuses and the other ones. They burn up so quickly and so easily that, of course, we would like to have them; but can we afford to?

Mr. Sachs:—That is certainly a very important consideration. This superior operation is all very nice—we hear from all sides—but what is it going to cost? The only answer is that superior operation has undoubtedly superior value. The enclosed fuse is more expensive than the type of open fuse heretofore used, but its advantages are so strikingly superior that the additional cost is, to a very great extent, offset. When you consider that you are gaining features unattainable in prior similar devices, accuracy and absolute safety, it certainly seems that you can afford to pay a little more for such protection. Insurance of the nature provided in an enclosed fuse certainly possesses a value.

Mr. Louis W. Downes:—I have been very much interested in Mr. Sachs' paper, for the reason that in the past six years I have been investigating in identically the same line; in other words, studying and developing the enclosed type of fuse; and I will state frankly that I am a believer in the air-drum type of fuse as against Mr. Sachs' principle of a solid-packed fuse, and I have had the opportunity of having many very pleasant discussions with Mr. Sachs on that subject.

There are certain points in his paper that I should like to bring forward for discussion, and certain explanations in regard to the air-drum fuse, which I believe will be of interest. There is one point on page 141 that I would like to call attention to, where he speaks of the enclosed fuse with the air-drum being subject to the same disadvantages of slow oxidation that an open fuse would be. As far as my personal observations have gone, this effect of slow oxidation is negligible in every practical sense. We have had fuses in practical operation, what I might say commercial operation, now for the past four years, and I have tested from time to time fuses that were made four or five years ago and which have been subjected at intervals to current, or to load I might put it, and have found no variation in their carrying capacity whatsoever. Examination of these fuses shows the same results. In other words, the amount of air contained in the air space is so extremely small that the oxygen present is not sufficient to cause any appreciable oxidation of the metal, and I think Mr. Sachs has rather exaggerated that danger. That is, I am simply quoting my own observations in that line.

He also speaks of the variation in the carrying capacity and the time element which can be produced by varying the air space, and I would like to add somewhat to that and state that the material used for filling also has a very pronounced effect on the time element for any given overload. It has come recently within my observation, in fact, only last week I was making some calibrations on fuses and I found that the variation in the material with which the fuse tube was filled affected the blowing time, at 50% overload, about 125%; and also found with what we call the multiple link fuse, which is shown in Fig. 10, on page 142, that the position of the individual links or strips of fusible metal also affects the blowing time on any given overload, that is, if they are spread out near the surface, with the air space of precisely the same length, you could get a much more sluggish fuse, (or, in other words, the time element is increased) than you do where they are drawn closer together near the center. This is obviously due to the fact that there was less material through which the heat passes to the surrounding surface in order to be thrown off, and in that way we possess possibilities of producing a fuse, within certain limits, of almost any desired time element.

Another point that Mr. Sachs speaks of, in mentioning the metal used, is of interest and importance. In my experience there are very peculiar properties in different metals when subjected to extremely heavy overloads, or those conditions approximating short-circuits where the metal is volatilized practically instantaneously. Some metals apparently can pass from the metallic state to a vapor with very little disturbance, very little of the explosive action that is present with others. I think copper, as Mr. Sachs states, passes with greater difficulty from the metallic to the vapor condition than any other metal that I have come in contact with. I have tried all the common metals. There seems to be explosive force or action there that it is almost impossible to confine. Pure lead, that is, commercially pure lead, passes with great ease, and zinc possesses very pronounced qualities in that direction. Even an exposed zinc fuse can be short-circuited with moderate capacities very successfully, without any great disruptive effects or burning of terminals.

On page 145, Mr. Sachs speaks of the extremely rapid oxidation. I think that it is not wholly a matter of oxidation in this case, because it appears to me that when the metal is converted into a vapor, that can hardly be termed an oxidation, in the strict sense. It is a metallic vapor, certainly, but it does not possess any of the appearance or nature of the oxides. It is that vapor which being condensed by the surrounding mass and being disintegrated by the surrounding mass passes off and prevents the establishment of an arc.

He speaks of short-circuit tests on 2500-volt alternating and 500-volt direct. I had some peculiar experience in that same direction myself, and I am inclined to think that the effect Mr. Sachs noted, that is, the burning of only a small portion of the strip in the alternating current short-circuit, was due more to an effect on the generator than anything peculiar about the current itself. One night in my laboratory we were going to try a short-circuit test. It happened to be in the winter-time, about five o'clock, and it was rather dark. We tried it and all the lights went out all over the city, and there was naturally a good deal of disturbance. They died down for a short period when the fuse blew, and immediately came up. Apparently the fields of the alternator had been killed momentarily, and I think that is where the result that Mr. Sachs noted came about, although the generator that I speak of was 500 K.W., and the fuse I blew was only 20 amperes nominal capacity, so that the generator was amply big enough to put out the energy, if it had not been that the sudden rush of current reacted on the fields and killed the voltage, so that the voltage across the fuse was extremely small.

MR. SACHS:—That would be a lagging of the current. You note I state here: "It may be due to the inability of the 2500-volt A.C. arc to maintain itself over a greater distance and also to the lagging of the current rush." It doesn't matter if the fields were killed, or whatever caused that lagging.

MR. DOWNES:—I suppose you used the word "lagging" of current in its general, technical sense, that is, lagging of the current behind the E. M. F, under which conditions the current might maintain its full value but come after a sufficient time element.

MR. SACHS:—I should better have said a lagging of the energy rush impressed on the fuse. When I used the word "lag" I meant choking off. Pardon me for interrupting, however.

MR. DOWNES:—I also found that it was possible with those generators, which, I will state, are separately excited, single-phase alternators; we actually found that it was possible to short-circuit or place a 30-ampere fuse directly across the mains and close the circuit without instantly blowing the fuse. That was at 2200 volts. It was possible to close that switch by the hand and open it again before the fuse had blown, so instantaneous was that killing effect on the fields. I would not advise any one to try that experiment with a compound-wound alternator, however.

Another very curious effect Mr. Sachs speaks of, where he mentioned that a portion of the fuse metal was surrounded, part with this active material and part with inert material, showing that the fuse blew where the active material was, and not at a point where it was surrounded by the inert material. I am inclined to differ with Mr. Sachs somewhat in this matter and to attribute the blowing of the fuse at the point where it was surrounded by the so-called active material to the fact that this possessed less heat conductivity than the other. In other words, the heat at that point was conveyed away less rapidly, and consequently there was what might be called an accumulation of the heat with rising temperature which brought about the results, namely, the melting of the fuse at that point, because that became the point of maximum resistance and temperature.

There is one point that I should like to second Mr. Sachs in most heartily, and that is in respect to the present method of rating that is advocated by the underwriters. It does not meet with my approval at all. I believe that there should be action taken on this in order to put out fuses marked at what they are, and not at some other value. In other words, let us call a one-inch pipe a one-inch pipe, and not mark a one-inch pipe three-quarters of an inch. Mark a fuse for the maximum current that it will carry continuously with a standard temperature, say, 75° Fahr., surrounding air, and you know definitely what you have got. The blowing point can be made for any given overload suitable to meet the conditions of the service, a matter which should be left to the manufacturer.

Mr. H. C. Wirt:—I am sorry to have to differ with both Mr. Sachs and Mr. Downes in regard to the rating of fuses. I think we should rate fuses in a commercial way, so that the public using those fuses can be assured that a circuit will always carry what the fuses are marked. I think if you rate a fuse to different time elements that the people who have to use these fuses will not understand them. I have had considerable correspondence with the underwriters regarding the 25% overload, and thoroughly endorse their decision. In fact, I advocated it. I think the fuses should be marked so that they can be used in the ordinary commercial cut-outs and to be certain that they will carry the rated current. I think as soon as you begin to mark fuses 5% overload and have them melt at that point you will get fuses that will melt when they should not melt. You have to make allowance for temperature. Some have to run in boiler rooms, others in cool places. The question is whether a fuse with 25% rating will cause any trouble to any wiring or impair the devices that they are to protect.

I have made investigations and found that under those conditions the wires are not overheated. I think that much of the discussion regarding the open fuse has been conducted with only an imperfect idea of the conditions. For instance, the open fuse has been blamed, because it will allow 100 amperes to pass through for a short time if it is rated for 50 amperes. I think that is no objection to the open fuse. I think enclosed fuses would do the same thing. The question is if under instantaneous load of 100 amperes the wires which are protected by the fuse will be overheated. My investigations show that under those conditions the wires are not heated as much as under the condition of a slight overload of 10%, or 15%, or something like that. I think there are two objections to the enclosed fuse. One is the cost; I think that is a very great objection. The other is the destruction of the fuse on short-circuit conditions. Mr. Sachs will probably say that that will not occur to his fuse. I know Mr. Downes will say so; but I have tested fuses made by both of them (and I anticipate what the gentleman will say) and I know that a 100-ampere fuse of either type will be destroyed under short-circuit conditions. I acknowledge that short-circuit conditions on many of the open fuses will be much worse, but I think we should all realize the limitations of the enclosed fuse; what kind of an enclosed fuse can be supplied to carry 1000 amperes, 500 volts? I don't know of any enclosed fuse that will do that work.

Mr. Sachs:—What was that capacity?

Mr. Wirt:—1000 amperes.

Mr. Sachs:—At 500 volts.

Mr. Wirt:—500 volts under short-circuit conditions.

Mr. Sachs:—Do you limit the capacity back of it?

Mr. Wirt:—No.

Mr. Sachs:—Do you place any limit on the capacity back of it?

Mr. Wirt:—No; if you are going to have short-circuit conditions, you must have big capacity back of it. I will give figures on a 100-ampere fuse. I do not know the current, but it is a very large current, of course, and those are conditions that will have to be met I have tested fuses on a 400 K.W. generator, short-circuited an enclosed fuse near the machine, and the cut-out was destroyed, and if any one had been near the cut-out there would have been danger of serious injury.

Mr. Sachs:—If you will pardon me for interrupting you again—was that an over-compounded alternating machine?

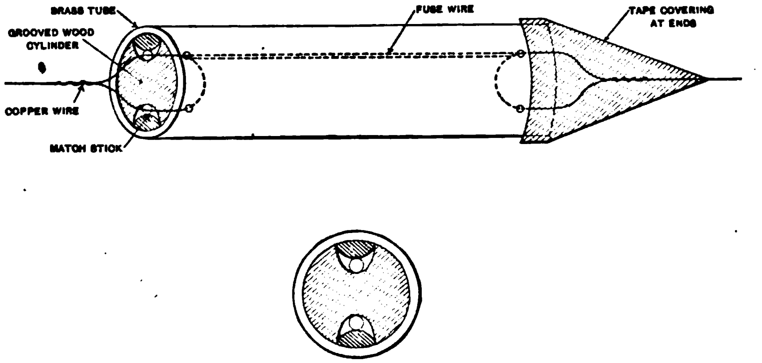
Mr. Wirt:—No; a direct current 500-volt machine.

Mr. Sachs:—Over-compounded—street railway service.

Mr. Wirt:—No; it was a rotary converter. Now as regards the objection to the fuse on account of the cost, I would say that if you stop to consider the cost of the enclosed fuse, for a railway car, which must be about 20 cents, and the number that are blown out annually in the United States, and then consider the cost of the simple lead fuses (which are used in a magnetic fuse box, causing them to operate properly) you see that the enclosed fuse is much more expensive, and as the lead fuse is enclosed within a box, it seems to me in the strict sense of the word that it is as much of an enclosed fuse as the strictly cartridge type; that is, there is no fire given out and no trouble owing to the construction of the fuse box.

It would seem to me that Mr. Sachs' test of the two fuses here, showing that the enclosed fuse operated quicker than the open fuse, was not just right, because we do not know for what overload capacities the two fuses were designed. If the enclosed fuse was designed for smaller overload capacity, of course, it would melt quicker. I am an advocate of enclosed fuses where they can be used, and where they are of an advantage; that is, I advocate them generally for 220-volt work and where the fuses have to go in buildings, where the trouble from leaking is great. I think in a case of that kind we should not mind the increased cost. But I do not believe that the enclosed fuse can be used in every position.

MR. WILLIAM J. HAMMER:—I think Mr. Sachs' paper is a valuable addition to the literature on this subject, and if I may be permitted I would like to call attention to a contribution to the enclosed fuse development, which I do not think very many of the members here are familiar with, and which came up in connection with the very early days of electric lighting abroad, many of these fuses having been used in both England and Germany. I would like to make a little sketch on the board. As some of the members perhaps are aware, "The First Central Station for Incandescent Electric Lighting in the World" was the Holborn Viaduct Station in London, England, which was started nearly a year before the Edison Pearl Street Station in New York City (*i. e.* Jan. 12th, 1882), and was a complete central station, employing four Edison "Jumbo" steam dynamos, Edison underground tubing, electric meters, indicating and regulating devices, and both incandescent and arc lamps, the latter, together with storage batteries and motors, being used experimentally. At the time when the Holborn Viaduct Station was inaugurated it was customary, both in isolated lighting and upon that central station plant at the time, to always put the switch on



CROSS SECTION

FIG. 25.

the one pole and the cut-out on the other, because there existed no double-pole cut-outs or double-pole switches at that time. It was customary for the man in putting in an installation to stand (metaphorically speaking) with his back to the dynamo, and take one wire in his left hand and the other in his right, and put his switch always on the right-hand wire and its branches, and put his cut-out on the left-hand wire and its branches or taps. In the Holborn Viaduct Station we found that it was advisable to put a fuse on the other wire as well. They were of the type shown in Fig. 25, and it is interesting to note that the Holborn Viaduct itself was the first street in the world lighted by incandescent electric lighting and Dr. Parker's "City Temple" church on that street was the first church illuminated by the incandescent lamp, and these were fitted with this type of fuse. It is a very simple form of an enclosed fuse, consisting of a piece of brass tubing, inside of which is a cylinder of wood. The fuse wire lies in the groove as shown. Sometimes it laid on both sides. There were a good many of them made with multiple fuses. Laid in the groove on top of the fuse wire was a little piece of wood, like a match, which very nearly filled the space. The copper wire at each end of the wooden cylinder was passed through a small hole near the end and was fastened back on itself forming a loop, with the fuse wire running from one wire to the other, and if multiple fuses were employed, fuse wires were put in grooves on both sides. (Another form used considerably, and which was the first form of "bug cut-out" ever used in inside electric fixtures, is shown in Fig. 26.) Much important pioneer work was done at the Holborn Viaduct Station. Some of the first insulating joints on gas and electric fixtures were made and used over there. Some of the first switches and circuit-breakers for use with heavy currents and a good many other things that have come into com-

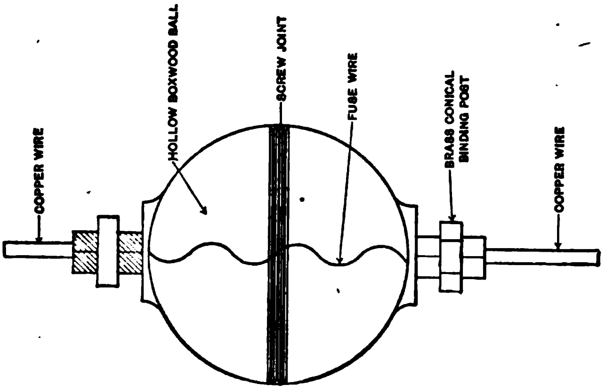


FIG. 26.

mon practice were tried there on a more or less extensive scale. This fuse had many advantages in addition to its being a very simple and inexpensive thing. The ends were usually wrapped around with tape. All that was necessary, if that fuse blew without destroying the whole fuse or making it necessary to put another one in, was that this brass tube be slid along the wire, the match lifted up, the new fuse wire put in and the sleeve slipped on again. Barrels of these fuses were used in both England and Germany in the early days of electric lighting, the fuse wire being 60% lead and 40% tin.

I note that there is a picture in Mr. Sachs' paper of one of Mr. Edison's early fuses or lead plugs. I hold in my hand one of the very first ones of this type, which is most interesting historically. The first incandescent electric lamp which was ever lit from an incandescent electric lighting station was connected with this identical fuse plug. In that case it was used as a switch. On the occasion of the first lighting of the Holborn Viaduct Station, which was January 12th, 1882, the circuit was closed with that little fuse plug, by my own hand, in the presence of a gathering of eminent men, and I at once removed and tagged the plug as you see it here and have kept it ever since; the first capped plugs came over to England shortly after the above date. Mr. Edison sent a cablegram shortly after their arrival, which read: "Vapors of a conductor are also a conductor. Punch a hole in every one of the safety plugs." I remember that cablegram very well. Mr. Sachs' paper and his references to vaporized conductors reminds me of it. This showed that in those early days of 1881 and 1882 they really appreciated quite a little the importance of the fact that the vapor of a conductor was also a conductor, and that it was a matter of serious moment in the Edison fusible plug, and we at that time appreciated that it was of importance to fuse all circuits, and especially to fuse both poles of each circuit, the desirability of which had not been realized up to that time.

Mr. F. V. Henshaw:—We have always thought the subject of fuses rather a simple one, I think, in the past, but it certainly is quite otherwise, and among the many interesting features of these enclosed fuses, I think about as interesting as any is the matter of the filling of these tubes. I have seen a great many experiments in enclosed fuses, and the results sometimes were rather terrific. I was very much interested in Mr. Sachs' description of his active material which combines with the oxide of the metal. Now, in the experiments which I saw, it struck me that that is precisely what you did not want. Some of these tests were made on tubes filled with various silicates and a condition which gave a most violent arc resulted, and after the thing had cooled down a beautiful little tube was found, vitrified on the inside and rough on the outside, and as long as that tube was there the arc would simply roar away inside. Further experiments show that substances that were incapable of melting or of forming any slag acted in quite the opposite way and the arc was choked out completely. So I was surprised at the fact that this substance which combines with the fuse metal has been found to be an advantage.

Mr. Downes:—Speaking of the results Mr. Wirt got from this 100 ampere fuse, I would like to say that a good many of the difficulties Mr. Wirt experienced have been overcome, and we are making fuses now which I will not hesitate to subject to a short-circuit at any time. A few weeks ago I had occasion to make some short-circuit tests and they all happened to be on 100-ampere fuses. I spent several days in the laboratory working on that, and short-circuited, repeatedly, 100-ampere fuses without any difficulty whatsoever. There was no arcing, no disruption of the fuse or parts of the fuse, or the fuse connections in any shape or fashion, and there was no lack of energy back of the fuse, because I had two 500-K.W., 500-volt generators running in multiple, and also in multiple with this was a very large storage battery; so that the instantaneous current was something enormous. These effects are accomplished by providing the fuse with suitable vents to take care of the vaporized metal. If you try to enclose a fuse, no matter what filling you put into it, whether it combines with the metal or whether it does not, and totally enclose it and don't allow escape for the gases under short-circuit conditions, it will invariably explode; that is, I mean, in the larger capacity; and explode with terrific violence. If, however, you provide that fuse tube with vents at suitable portions,—do not put it at the immediate center,—you can short-circuit the fuses of large capacity with perfect safety.

In speaking of the effect of material combining with the fuse metal that Mr. Henshaw has just mentioned, I would like to state that I observed very curious properties in certain materials that tend to suppress arcing. I have made tests in that direction, trying almost every material that I could find mentioned in text-books; that is, material that was sufficiently cheap to be utilized for the purpose, and find that some possess very pronounced and remarkable properties towards suppressing an arc. The tests were made in this way: A small glass tube was provided with a metallic bottom and a plunger, a small copper wire was run down through the top, and the material that the test was made on was put into this tube, and contact was made by pressing the plunger down until it struck the bottom. The current used being on a 500-volt circuit with lamp-bank as load. To establish the arc the plunger was drawn slightly away from the bottom. With certain materials there was a tendency to aid the arc, largely due to the reduction of the surrounding materials and the presence of the water of crystallization, which tended to carry over the current and maintain an arc. With other material as soon as the point was drawn back the arc would be almost immediately extinguished. I have not been able to determine just what that effect is due to. But I attribute it to the presence of certain gases that are formed in the first flash on the circuit as the plunger is drawn away.

MR. C. O. MAILLOUX:—The troubles which we find with fuses in isolated plants are largely increased with the voltage. The introduction of the 220 volt two-wire system, that is to say, the use of 220 or 230 volt lamps has necessitated the making of cut-outs which are suitable for that voltage, and the difficulties due to arcs at the cut-out panel have greatly increased; one might be tempted to say that they increase in a higher power than the square of the voltage. It is in such cases that a fuse that can be depended upon to go off at a certain fixed excess of normal rate is valuable, especially if it can be depended on to go off without setting off the rest of the cut-out fuses. It has often come to my knowledge within the last two years that an ordinary cut-out of the "panel" type, in which the fuses are connected between bus-bars, has had all the circuits on one side blown out by the operation of one single, innocent 10-ampere fuse. The disruptive effect is very great, and then the arc is necessarily longer, owing to the higher voltage, and that arc is apt to rise until it starts a short circuit, which produces the same result across the next pair of bars above, and we have a "blow-up" process which starts at the bottom of the panel and ends at the top. In some cases the amount of vapor produced might be sufficient to force open the cabinet door. We may find in an establishment, for instance, where motors are run, a fuse that is rated for 25 or 30 amperes. Suddenly the motor is overloaded or stalled and the fuse blows. The current at which the fuse blows may not exceed 75 amperes, yet it has happened that in consequence of that 75 amperes the whole establishment has been shut down and had its current supply cut off, because that 75 amperes would cause a larger fuse to blow perhaps on the main or on the feeder, or even go as far as the switchboard. and if we are unfortunate enough to be operating with a closely loaded plant and have electro-magnetic cut-outs which have not much margin in their adjustment, the result will be that one of the machines will be cut out by the action of the circuit breaker. Instantly the others are all overloaded beyond their capacity and they will also become cut out. I have heard of similar instances which have occurred, and in one case it was found necessary to screw the weights or springs of the electro magnetic cut-outs until they became practically inoperative; that is, until their capacity was at least 100 or 150% above normal load. It seems to me that the enclosed fuse will have a great sphere of usefulness in cases of this kind where safety and especially where reliability of service are conditions which dominate all considerations of price and of cost. There are difficulties, however, which still remain to be met, and these are the methods of connecting the fuses. It does not seem to me that the mechanical conditions are properly met or provided for. The terminals do not get as good contact as they might. I have seen cases where the contact of the terminals to these protective fuses was such as to become warm. It would produce heat perhaps enough in some cases to operate the fuse. There does not seem to be that interchangeability between the various fuses which is the desirable feature in all American work where all like parts are made interchangeable. I have found these arcless fuses very useful and in fact have found them indispensable in many cases even as they are. I have had to use them where all other methods have failed. But I think they are still far short of the sphere of usefulness to which they will attain, when the mechanical details, especially the methods of making terminal contacts, have been worked out a little more perfectly and satisfactorily.

Mr. Fremont Wilson:—There is not much I can say that has not been covered by my old associate, Mr. Mailloux, except that I might refer to Mr. Dunn's question as to first cost. It is a very pertinent question. I sent for Mr. Sachs some time ago and asked him to go to one of the large hotels in this city and see if he could not induce the proprietor to put in his fuses. I had been about driven distracted with arcing of 230-volt fuses, and the question of cost came up, and as is known all hotel men are fiends on cost. They never look at the cost in the proper light as we consider it. Mr. Sachs was very neatly turned down. The fuses have not been introduced, but they will have to go there, because the panel-boards are being disrupted very rapidly. The proprietor uses a cheap make of lamp. He won't buy what may be considered the only lamp there is that will work on the 230 volts; it is unnecessary to mention the name of it. The lamp he uses, short-circuits across the base with the result Mr. Mailloux has just stated, and although the circuits are protected by so-called 10-ampere fuses, time and time again a feeder circuit breaker of 100-ampere capacity has opened, and in one case a main circuit breaker opened and threw a 150-K.W. machine out, and one-half the hotel was in total darkness, owing to a lamp short-circuiting across the base. With Mr. Sachs' fuse such a thing is absolutely impossible, as I see it. I have tried to get people to use it, but they come back to the cost. But they have got to come to it, and Mr. Sachs has simply got to be patient, as lots of us have had to be. They are bound to win out on isolated plants. The circuit-breakers we have now are so delicate, operate so quickly, and the short-circuit develops such an enormous rush of current momentarily either in the lamp-base or in the socket that you must have something of this sort. I have to deal with the question now as engineer for several insurance people, and the question of to-day is, what are we to do with panel-boards where they have the ordinary fuses on 230 volts? and I have had to make a recommendation and do not know where I am coming out on it, to take out the panel-boards and put in ones with the enclosed fuse, such as we have here to-night.

Mr. Mailloux:—I wish to add a few words on a point which was the principal point I previously intended to discuss and which I forgot. I am in doubt as to the expediency of providing cut-out devices for the generators when they exceed a certain size. As you know, in central stations no one thinks of putting in fuses unless they are so set or so designed that they will only give way at the actual burning or destruction point of the machine. In very large installations I think that more harm may occur from having a large unit cut out as the result of overload than would result if it were allowed to run overloaded. This matter was of very great importance, especially in a case like the Astoria Hotel, where an occurrence such as I described a little while ago wherein the operation of one fuse led to the successive cutting out of all the dynamos and threw the whole establishment in darkness, would be simply inadmissible—it would cause a panic and might result in the loss of many lives, to say nothing of the discomfort, inconvenience and annoyance it would cause. At the time that the Astoria Hotel plant was designed, the matter was very seriously considered and discussed, not only with the owners but with all parties interested, even with the insurance authorities, and it was deemed, on the whole, best to make the arrangements such that the machines would operate substantially the same as under central station conditions. The fuses were placed at the rear of the board, where, if they did go off, they would not hurt or blind anybody that happened to be in front (for no one contemplates with very much pleasure the going off of a 300-kilowatt fuse), and they were so proportioned that they would take about twice the normal capacity of the machine to fuse them. But as it would not be pleasant to operate with 100 or 150% overload, a relay device was introduced in one of the dynamo leads and so arranged that it would operate and close a local circuit and ring an alarm-bell and show a red light. It seems to me that this method of giving the attendant a hint that it is time to reduce the power or to do something is much better than to shoot off a cannon, and it is probably not more dangerous. I believe for myself that when we reach a unit as large as 100 kilowatts it is time to trust more to the care of the attendant and his ability to act in an emergency than to trust to automatic cut-outs or fuses, because I think that their unexpected action, their going off at the wrong time or at a critical moment, is likely to produce far more mischief than even the burning out of an armature or the destruction of the machine itself. It is certain that in a case like the Astoria Hotel the owners would far rather pay for a new armature or a whole new generator than have to pay the damages that might result in consequence of a panic due to the sudden failure of the current supply. There are numerous other similar cases. The Astoria Hotel illustrates the point, because it is the largest isolated plant in this section. But the same troubles occur to a greater or less extent in numbers of installations where the plant is much smaller. I think it might be well for the INSTITUTE to consider this matter, since the insurance authorities are likely to be influenced by our views in the prescribing of rules on the subject.

MR. W. C. WOODWARD:—The plant with which I am connected as engineer is to-day the largest plant in this country, operating a 470-volt 3-wire system, using 235-volt incandescent lamps. The plant consists of direct-connected generators in units of 500 kilowatts, operating in multiple with a storage battery system of a capacity of 760 amperes on each side, discharging into the 3-wire lighting system, the network of main conductors in this system being underground in all cases; the feeders the same. Of course in designing this system it became necessary to provide for the difficulties that had been encountered in the 3-wire system of 220 volts on the outside, recognizing, of course, the fact that the troubles would be magnified very largely in the case of the higher voltage. New devices had to be designed, and they were designed theoretically entirely, as there was no practical commercial data on which to base calculations. It became necessary to introduce currents of large capacity and high voltage, protected by fuses, and the enclosed fuse was used in every instance through the entire installation, both underground and in the consumers' premises. I will state that the fuses have operated on several occasions and operated as it was intended they should. I will substantiate Mr. Sachs' statement that copper gives a much more destructive result at the terminal than aluminium. We have short-circuited bus-bars and mains with copper, producing dead short-circuits, and the protecting fuses in every case have blown. Where the bus-bars have been actually short-circuited by copper strips, of course there has been considerable destructive arcing. Where it has been aluminium the arcing has been less destructive. We find no trouble in the 235-volt enclosed fuse, and I think that Mr. Sachs can be substantiated at every point, as far as the enclosed fuse is concerned, that it is the only device that should be used in breaking circuits of high voltage, or, in fact, of any voltage.

MR. STEINMETZ. [Secretary Pope in the chair.] I shall confine myself strictly to the topic of the paper. The paper and the discussion following it have been very interesting in dealing with fuses suitable for circuits of moderate capacity and relatively low voltage. For such circuits fuses are generally and successfully used, but I must caution you not to generalize too much, as has been done by the author and by many of the speakers, regarding the use of fuses, especially in circuits of large capacity and high voltage. Fuses, circuit-breakers, switches and other protective devices have the common feature that judgment on their value can be derived only by experiment, or tests, and that such tests are rather difficult to make, and the facilities for reliable tests are not always, or even rarely, available where large powers and high voltage circuits are considered, and furthermore that the liability to be misled by inconclusive experiments and thereby to arrive at erroneous conclusions is extremely great, as great almost as it is with the primary battery.

For instance, in the paper as read, and by many speakers, reference has been made to the short-circuit tests of fuses. Now the mere short-circuit test of a fuse is entirely valueless regarding the action of the fuse. I refer here to fuses intended to control large power; short-circuit tests frequently are more than valueless, they are misleading in so far as they are liable to make the fuse appear to be able to do a thing which it is not able to do. Take for instance, the tests given here in the paper as referring to a fuse on a 2500-volt alternating circuit and a 500-volt direct current circuit. Now this should read, "the tests of a fuse on a circuit on which, before the fuse was connected, 2500-volts alternating existed, and after the fuse was connected a very small voltage, very few volts existed and a current limited by the armature reaction, or the short-circuit current of the alternator, that is a current of unknown value, but probably quite moderate, was flowing until the fuse ruptured, and after the fuse had broken the circuit, the voltage gradually, with an unknown velocity, rose again to the initial value."

You see, instead of taking the trouble of short-circuiting a 2500-volt alternator, you might short-circuit a few storage batteries with the same result. The result depends entirely upon the short-circuit capacity of the alternator and upon the speed with which the alternator, after opening the circuit, recovers its voltage. That is, the test gives nothing regarding the current and the voltage ruptured by the fuse. This is the reason why in the test referred to the action of the fuse was much more violent on a 500-volt continuous current circuit, merely because in the 500-volt continuous current circuit, with the large magnetic field of its generator, the magnetic field held on after the fuse blew, and the voltage recovered rather rapidly after the blowing of the fuse, while the alternator with its high armature reaction and relatively weak field entirely lost its voltage and only later recovered after the fuse had already opened the circuit. This explains the discrepancy of opinion on the action of the 100-ampere enclosed fuse which, according to Mr. Sachs, should rupture a 500-volt circuit, and according to Mr. Wirt merely blow to pieces. Mr. Wirt put the fuse on a rotary converter which transforms from an alternating system of unknown but probably very large capacity, while Mr. Sachs had only small power behind the fuse.

So you see short-circuit tests are misleading and rather meaningless, and the conclusions derived therefrom regarding fuse-protected circuits are not safe.

Let us then see how we should test a fuse to see whether it is reliable. One way would be if you want to make short-circuit tests to short-circuit a long line, or better a cable, at the receiving end by the fuse, with such generator capacity at the other end of the cable that with the short-circuit on one side the voltage is maintained at the other end. Then, while the voltage drops down to zero by the short-circuiting of the fuse, in the moment when the fuse ruptures, the voltage instantly recovers because it is constant at the other end. You see here you get the maximum velocity of voltage recovery. If you can rupture such a 2500-volt circuit with a half-inch fuse it is more conclusive than to short-circuit a Niagara generator for instance, by it, since the generator drops down in voltage. A still more severe test, a test however which represents conditions very frequently met, is not to short-circuit the system but to insert the fuse between a generator and a synchronous motor or converter, and then gradually load the converter or synchronous motor until the fuse blows. That is, see whether the fuse ruptures the circuit between a generating system and a receiving system, which latter contains a live counter E. M. F. What you get in the moment of rupture is this: While the fuse is still there, the generator of say 2200 volts sends current through the circuit against the counter E. M. F. of the synchronous motor of say 2000 volts. When the fuse melts and the circuit begins to open, the generator and the motor maintain their E. M. F.'s, but rapidly, due to the opening of the circuit, the current decreases and the synchronous motor begins to slow down. It drops one-half wave behind, but then the 2000 volts of the synchronous motor are not in opposition to the 2200-volt generator, but are in phase and you have 4200 volts across the fuse. That is, the voltage is practically doubled, and if you can break away then with the fuse you can rely upon it, but not if it opens a circuit after the circuit has lost its voltage.

But there is one feature to be considered, which was not brought out by the paper, because the paper really is based on experience with relatively small capacities and small powers, while this feature is the dominating feature in circuits of large capacity and high power. That is, the fuse or other protective device must open the circuit so as not to endanger the circuit. Where you have a circuit containing cables or long distance transmission lines of very high voltage, you can not safely rupture the circuit instantly. The first condition of any circuit-breaking device is that you open the circuit so as not to cause any excessive rise of voltage by resonance between capacity and self-inductance. This greatly limits the action of the circuit-breaking device, and it is a condition which practically excludes fuses from all such circuits, or at least makes them rather undesirable. The action of a fuse is not a gradual opening of the circuit in a high potential circuit, but in the moment when the fuse blows, an arc starts and holds on, with increasing length flaring up until it suddenly breaks. The decrease of current is first quite moderate until the moment when the arc ruptures, and then you get a sudden break of current which causes an oscillating discharge and destroys your cable, or at least makes a pin hole, and the next day another one, and after half a year or a year, the cable begins to break down, and these break-downs occur with increasing frequency, until the cable has to be replaced. The result is that as far as possible in high voltage circuits, fuses and other overload protecting devices are not used, but a rigid connection between generating system and receiving system, and special care taken to make it impossible to open the circuit while alive. Obviously where the central station feeds a number of cables or distribution lines and the liability exists of troubles in one circuit or the other, you must be able to break away from the system, and there you have to design a circuit-opening device which opens gradually and slowly enough not to cause a dangerous rise of voltage. Attention has been drawn to the explosive effect of fuses and how to guard against it. A certain violence, however, is inherent to and unavoidable in opening circuits conveying large powers; if we control a high-voltage large power alternating system, we have seen that we must not open circuit instantly, because instantaneous break of the circuit causes liability to destruction of cable, transformers, etc. The circuit-breaking device must open the circuit gradually, during a time in magnitude comparable with the time of one-half wave. That means in a 25-cycle circuit comparable with one-fiftieth of a second. Consider what power you develop at the point of break if you open a short-circuit gradually, that is, during one-hundredth of a second, on a large power distribution system as that for instance of the Metropolitan Railway here in New York City. At the point of break, power is developed about equal to the explosion of some ounces of gunpowder. Then it is not possible to open the circuit entirely without explosive effect.

You see then that the conditions as soon as you come to a circuit of very large capacity and high voltage, are entirely different from those experimented with by the reader of the paper, and all other considerations are entirely overpowered by the condition that you must open the circuit under any condition, and that by a device which will open without resonance rise, and by expending during the opening as much power as is developed during the time of opening; that is, during a time comparable in magnitude with the time of one-half wave or one-half period. I do not know whether fuses can be made to do that, but I very much doubt that they can, due to their inherent feature of opening the circuit suddenly.

Mr. Sachs:—Mr. Steinmetz's remarks are certainly pertinent to the paper. They speak of things that I have not done yet, but I am perfectly willing to do. I have not been afforded the facilities to short-circuit at the end of a mile or two of underground cable, for the simple reason that nobody would furnish the cable. I feel sure, however, that I can open a circuit under such conditions with less injury to the cable than, perhaps, Mr. Steinmetz considers fuses capable of doing.

I have not been able to short-circuit a system of the size of the Metropolitan Company's system, for the reason that neither the Metropolitan Company nor anybody else wanted to deliver over their system for this purpose—at least not in its entirety. You appreciate thoroughly that the first experimental device may miss fire. It is then simply a case of blowing up the system or blowing up the fuse.

In regard to gunpowder and gunpowder fuses, Mr. Steinmetz, when he made that remark, had, as we perhaps would say, quite a good deal more than that remark up his sleeve. Mr. Steinmetz has recently invented a veritable gunpowder fuse. He has placed a fuse wire surrounded by some explosive compounds in a tube, and then blown the fuse wire inside of the surrounding environment, veritably getting the explosion that he desires. So, as you readily see. Mr. Steinmetz desires an explosion; he does not apparently want a fuse that goes quietly and nicely and properly.

Now in regard to what fuses will do and where they will do it and how they will do it, if you will kindly refer to my paper, I think it is at page 147, "it is, however, only necessary for a protective device" (fuse or otherwise) "to accomplish satisfactory results on the particular service in connection with which it is used." When a protective device is constructed to operate in a trolley car, for instance, or to operate at the end of a long-service line, protecting a converter or supplying a house-service, it is not supposed, and it is not necessary that that fuse should be capable of being thrown across the bus of a 10,000-K.W. station to stand the short-circuit there, as nobody would want to pay for a fuse for a converter service that would stand the latter service which in practice it would never be called upon to perform. Fuses to stand the excessively strong blows can be constructed and will operate without explosion. It is, however, essential to carefully consider size and arrangement. Some of the sizes that Mr. Steinmetz has named may be rather large, but I feel confident, from tests which I have made and from the experience in that direction I have had, that the energy thrown into a fuse of the type that I have shown you can be choked off and more or less absorbed and dissipated without bursting the tube, without exterior manifestation and without tearing the cable, the dynamo or the flywheel to pieces. If Mr. Steinmetz has any protective condition or proposition that he would like to have me try on, I stand ready at any time to take it up, and it simply remains for Mr. Steinmetz to furnish the apparatus. The test can be very carefully conducted by trying the fuse first under conditions of minor severity and gradually increasing the abnormal conditions. I do not expect Mr. Steinmetz to take a large generator and short-circuit a fuse across it before he knows exactly what it will do.

Mr. Steinmetz has said the capacity of the generator affects the device. I have stated that previously in my paper in the section on the general principles of excess-current protection, which I did not read. I discussed the generalities quite fully, and stated that too much stress cannot be laid upon the size of the generating capacity, the character of the generating capacity, the distance from the generating capacity at which the fuse is placed and operated, the character of the circuit and its impedance. I stated that the effect of a short-circuit or any abnormal current condition simply depends on the decreased impedance, assuming that the generating capacity remains at normal or rises in potential. Certainly where we have generating capacities that go down, the proposition is comparatively simple, and that is the point I tried to bring out—that too much stress has been laid upon the mere voltage feature. A 2500-volt circuit does not necessarily require an abnormally long fuse. It may be possible to use a shorter fuse than on a lower-voltage circuit where the generator and other conditions test the protective device more severely. The short-circuit tests of fuses, which Mr. Steinmetz says are valueless, because they simply can be specialized and not generalized, I cannot quite agree with. While it is a fact that there are overload conditions, a great many of which Mr. Steinmetz has named, that are more severe than a short-circuit test, yet it must be acknowledged that a device that can stand an instantaneous blow of the enormous amount of energy that must be instantaneously absorbed on short-circuit is certainly the device that *per se* will possibly hold a pretty good overload under similar service conditions. Fuses should be built to meet conditions and not necessarily voltages. Similar conditions of energy rupture may exist at different voltages. I have absolutely short-circuited a fuse having a continuous running capacity of 600 amperes, on one of the largest 500-volt street railway systems in this country, with enormous feeders, at a distance of only half a mile from the station, the station being one of two connected into the network of feeding conductors. I would also refer Mr. Steinmetz to page 151, where he will find a consideration of the gradual break.

In regard to Mr. Wilson's and Mr. Mailloux's remarks I will first take up the matter of trusting to the attendant to open the circuit instead of to a simple automatic device. Such trusting to the attendant may serve very well under conditions of gradual overload, but it does not take care of the short circuit. The short-circuit rush is quicker than the attendant, even though he may be lightning-like in his movements. A device which by means of a current relay notifies the attendant when to pull his switch or operate his regulator or to do something to take off some of the load is excellent; but there exists no such means of indicating to the attendant quickly enough the fact that somebody has dropped a screwdriver across the bus-bars on the switchboard or panel, or the occurrence of an equally severe abnormal condition. It would be better to have the device automatic. Simpler and safer automatic apparatus than a properly designed enclosed fuse is almost impossible.

In regard to the instantaneous operation of fuses on overloads, I want to draw the attention of Mr. Steinmetz and Mr. Mailloux to the curve shown on page 155, which clearly demonstrates that when the overload on the fuse becomes excessive, and only at that time, does the fuse operate almost instantaneously. Should the overload be a gradual one there is ample time for the attendant, who should be at the switchboard to notice that his ammeter is reading higher than it ought to and pull his switch or operate the generator rheostat to lower the voltage, even perhaps before the fuse is blown, if the fuse is properly designed for that condition. Let the ammeter serve as the excess indicator. I think it is an absolute fallacy to put in a fuse to act as a protective device which will continuously carry 100 or 50 per cent. above the capacity that the machine is supposed to stand, for some length of time, but beyond which it is injured. If the fuse carries it continuously it is not a protector for that machine or other device if the relations are as stated.

MR. MAILLOUX:—Does not pulling the switch reduce the E. M. F.?

MR. SACHS:—It is by no means desirable to instantaneously throw off the entire load carried by a large generating unit for various obvious and previously mentioned reasons. Such instantaneous break occurs when a switch is quickly opened, but the opening of a fuse of the character described is of another nature. Reference has already been made to the gradual increase in resistance of the structure between the fuse terminals which necessarily results in a more or less gradual break and buffing effect.

In substantiation I may refer to the tests of the indicator wire without the fuse and the action of the complete fuse with indicator (see page 153). It can readily be demonstrated that the fuse, at the moment when it starts to go, does not let go with an instantaneous drop, but with a gradual slide. The gradual break certainly must occur in a very short time-interval, but whatever that time-interval may be it is sufficient to ease the current-breaking effect far more than if it had been instantaneously choked off as in the case of electro-magnetic switch devices.

The advantages of a time-interval device such as a fuse for motor service need not be gone into here. The relative advantages of electro-magnetic devices, which are instantaneous, and time interval devices such as fuses, as applied to motor service, are well understood. I believe it is universally acknowledged that for the protection of the motor and for the service that it performs, except in certain particular conditions, where the machine driven has no time-interval overload capacity—such as a press, for instance—that a time-interval device is superior.

In regard to Mr. Wirt's discussion I must say that I certainly cannot agree with any rating of any electrical device, whether it be a fuse or circuit-breaker or dynamo or motor or anything, except at its continuous, constant running capacity. If we have a motor that will run at two-horse-power continuously why should we rate it at one? I do not believe that motor or dynamo manufacturers or manufacturers of any electrical devices are willing to half or three-quarter-rate their electrical devices, yet the liberal fusemaker tells us that he is willing to rate his fuses at only three-quarters of what they actually carry. In other words, we are getting more than we want. But getting more than we want under such conditions simply means that the generating apparatus or the motor or the wire may also get more than it wants or ought to have.

The matter of destroying 100-ampere fuses on a rotary converter under the conditions that Mr. Wirt has mentioned is simply a condition as I have already considered. Any apparatus or device, whether a fuse or anything else, should be built to meet some particular condition or service. In the case of a fuse or similar device this service involves the opening of an abnormal energy condition impressed upon it. It should not be expected to open several times its intended capacity. The 100-ampere fuses tested were apparently not intended to serve at the particular conditions of the test. But that by no means implies that similar fuses intended for such service are not available. It is simply necessary to provide different arrangements of the parts to produce the desired result. Mr. Wirt should not expect a fuse intended for some particular service to operate under any other. If Mr. Wirt will inform me of the conditions to be met, not only the voltage, I will guarantee to furnish him with a fuse that will operate satisfactorily.

The matter of whether expensive fuses are the proper protective device on a railway system, particularly in the cars, is a matter that I am especially interested in. It is a matter that I have given quite some attention to, and the fact remains that to-day we are able to sell in quite some quantities protective devices that cost three, four and five dollars apiece, whereas an ordinary open wire to perform the same service would cost perhaps five cents. Now that is an actual fact, and it is an object lesson, I think, that may indicate to Mr. Wirt the fact that the street railway manager is not simply looking for the cheapest device, but he is looking for the device which will permit him to operate his road most safely and satisfactorily. Mr. Wirt must remember that the first cost of an enclosed fuse is by no means the cost of using it. The refilling cost of the casing is not by any means an abnormal figure comparatively.

Now, with regard to Mr. Downes' statement and also Mr. Henshaw's statement in regard to the details of the construction of the fuses, I want to say first that the principles upon which the fuse which I have shown you this evening is based are peculiar. It has been a matter of a great deal of experimentation to arrive at the exact combination of elements that produces the present results. You might put, for instance, a silicious powder in a tube, thread a fuse wire through and produce a combination, but such a combination would produce exactly what Mr. Henshaw has said in regard to the formation of an envelope or a tube of silicate. The mere formation of a combination is not sufficient to produce an operative enclosed fuse. The character and form of the resulting commingling of the elements must be most carefully determined. This has already been emphasized in the paper.

Whether the blowing of the fuse results in a combination of the oxidized vapors and the filling material, or whatever other forms of the vapors may combine with the material, does not enter into the question at all. The fact is, that metallic vapors will oxidize, and the fact also remains that such metallic oxides will combine with non-metallic materials. In the matter of oxidation of an inclosed fuse strip that is surrounded by air, Mr. Downes must acknowledge that such a fuse strip enclosed in an air envelope is supplied and resupplied with air during the successive heating and cooling of the fuse. When the interior chamber is heated, the gases expand and the air is forced out. When the fuse cools, fresh air is forced in. So you are getting a continuous supply of air on the inside of the tube. I need not discuss the advantages of an oxide envelope formed around lead and tin fuse wires. That feature has been discussed in previous papers, and it is universally acknowledged to be a disadvantage.

The blowing of the 2500-volt fuse seems to have aroused some discussion; also the word lag. When I spoke of lag I meant the lagging of impressed energy or heat-producing effect. Whether this lag was due to the conditions in the dynamo or circuit matters not.

Mr. Downes has stated his experience in regard to the effect of the wire-surrounding environment on the carrying capacity of the fuse. This result will appear entirely obvious when the varying heat conductivities and capacities of the various materials which may be used as fillings are considered. The paper has made note of this feature as a particularly important one in connection with the design and construction of enclosed fuses. (See page 149.) Mr. Downes' idea in regard to the action of the strip shown in Fig. 16 is to a certain extent correct. It is quite true that the active material is a poor heat-conductor and permits the more rapid heating of the strip around which it is placed. This fact alone would, however, only result in a similar condition to that described in the test on page 141, in which the holding of the molten fuse wire in metallic continuity, when encased in an ordinary environment, was clearly demonstrated.

Fig. 16, however, shows that the wire in the center was entirely molten, but the rupture occurred at a point where, after the wire had attained a molten condition it was no longer permitted to remain in continuity, owing to the action of the peculiar environment at that point.

It is probably unnecessary to refute at length any statements relative to the accuracy(?) of open fuses. The opening chapters of the paper generally consider this proposition, and I believe the premises taken have good foundations.

In concluding the discussion I will ask your pardon in repeating the spirit of a former statement. Properly designed enclosed fuses can be constructed to open excess-current conditions in a manner unequalled by any other present form of protective device.

PROF. R. A. FESSENDEN:—I have an item of new business to bring before the meeting. A motion has been drawn up by several gentlemen who are interested in electrical units, as follows:

Moved, That the Committee on Units and Standards be requested to investigate and report at the ensuing meeting in regard to the advisability of the following:

1. The giving of names to the absolute units of the electrostatic and electromagnetic systems.
2. The denotations, by means of prefixes, of multiples of such units.
3. The rationalization of the present system by means of taking the absolute unit of magnetism as equal to the present magnetic line, and the absolute unit of difference of magnetic potential as equal to the present absolute unit of current-turn.
4. The advisability of taking up any or all of the above matters at the Congress to be held in Paris this year.

I have received the following letter from Prof. Elihu Thomson, seconding the motion:

SWAMPSCOTT, Mass.,
March 9, 1900.

TO THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS:

I desire to second the motion of Prof. R. A. Fessenden to request the Committee on Units and Standards to investigate and report upon the subjects mentioned by him in the accompanying motion.

ELIHU THOMSON.

It will not be necessary to have any discussion about this at present, I suppose, as it is late and as it is a matter for a committee to investigate.

It was voted that the resolution be referred to the Committee on Units and Standards, and the meeting adjourned.

[COMMUNICATED AFTER ADJOURNMENT BY HOWARD R. SARGENT.]

From the reading of the paper, experiments and discussion following, it would seem to me that the enclosed fuse has a large field for 250-volt or 500-volt work up to 50 amperes. This would cover the wiring of buildings, protection of small motors, etc. For larger work, especially station work, it would seem from the discussion and remarks of central station men present that the field for the enclosed fuse would be very small, on account of the cost, bulk and uncertainty of operation.

Mr. Sachs claims that a fuse can be made which will entirely enclose the arc and explosion, no matter how severe the conditions, but he does not state what the size of such a device would be. From tests which I have observed it would seem that the size must be excessive.

In connection with this, should a fuse of this type be built to stand the most severe conditions which can be imposed upon it, or should it be built to take care of a short-circuit such as would be obtained at a distance from the central station?

Referring to Mr. Sachs' remarks concerning the metal of the fuse itself, we presume, of course, that the reference to the oxidation of lead-tin fuse wires concerns only those commercial fuse wires which are made of practically pure lead. A lead-tin fuse wire which is very rich in tin will not oxidize under ordinary conditions.

From the table given on page 155 it would seem that a very objectionable feature of the solid-packed fuses is the variety of diameters and lengths. Each different length and in all probability each diameter would require a separate fuse block, and a central station manager or supply house would be obliged to carry an enormous stock, and in time of an emergency would probably find that the particular size desired was not at hand.

In the discussion Mr. Sachs stated that with the shunt indicating fuse there was an appreciable time interval in the rupture of the circuit. Does this not emphasize the fact that the indicating fuse blows after the main fuse has gone, and that the shunt fuse therefore practically aids in rupturing the arc and also forms a menace to any inflammable material near the cut-out.

During the discussion Mr. Downes stated that in order to take care of the more severe conditions, fuses of the enclosed type require vents, and an examination of the lecturer's samples shows that he has embodied this feature. Where then is the line drawn between an enclosed fuse and an open fuse? If these vents are to be placed in the ends of the fuses, are the enclosed fuses not as bad in certain ways as the open type? The public know enough to keep away from an open fuse, but it seems to me that a fuse as described above would resemble an ambush and lead to serious personal injury, if not to serious conflagration.

In connection with this subject I should like to mention a recent test which I had the pleasure of witnessing.

Vulcanized fibre tubes $\frac{3}{16}''$ thick, 5″ long, $\frac{1}{2}''$ inside diameter were taken, and solid plugs were riveted in the ends so that air chambers $\frac{5}{8}''$, 1″, $1\frac{1}{2}''$ and 2″ long were formed. After 30 amp. fuse wire had been inserted through the chambers, caps were riveted on the ends. These fuses were short-circuited close to two 400-K. W. 250-V rotary converters running in multiple.

The first and second fuses were totally destroyed, the third fuse had the plugs blown out, and the fourth fuse was left practically intact. This would seem to show that it is a valuable feature to have a large air space for the vapors formed and expansion which takes place; also that the larger body of air tends to form a cushion for the explosion. This experiment is merely mentioned on account of its being a rather peculiar one, and is not, of course, conclusive.

Schenectady, N. Y., March 30, 1900.

[COMMUNICATED AFTER ADJOURNMENT BY L. W. DOWNES.]

I can hardly agree with Mr. Steinmetz's assertion that short-circuit tests of fuses are not only valueless but misleading, for, while I believe that they do not in themselves decide absolutely the value of that fuse as a protective device, they do unquestionably determine its effectiveness under conditions which are not at all uncommon in daily commercial practice.

Assuredly, nobody can claim that short circuits, particularly in direct current lighting and power systems, are of rare occurrence. Quite the contrary, and a protective device to come at all within the requirements of commercial service must certainly be capable of handling such short circuits.

I heartily second Mr. Sachs' assumption in this matter, that the fuse must be tested under practical conditions and not under abnormal ones, or, in other words, the fuse should be designed for the service for which it is intended, and it is not at all reasonable to make a test, in the manner suggested by Mr. Steinmetz, using a synchronous motor. The conditions there that he described, viz., of heavy lagging current and the doubling of the voltage, are abnormal for any circuits other than those upon which such particular test is made. We certainly do not get such conditions in direct-current electric lighting. We certainly do not get such conditions for transformer protection. We certainly do not get such conditions in direct-current power work. Consequently, wherefore is it desirable that the fuse, which is used on these various systems, should be so constructed as to meet abnormal conditions which can never possibly occur on the systems for which they are specifically intended? On the contrary, fuses used for synchronous motor work must assuredly be designed to meet the peculiar conditions of the service, and it is quite within the possibility of the enclosed type of fuse, in my opinion, to construct them, so that they will operate satisfactorily, provided the current capacity called for is not too great.

I believe that all tests of fuses should be carried on under conditions which as nearly as possible approximate those which are met with in commercial service, and it is the practice in our laboratory to carry on tests in that manner. All fuses are first tested for continuous load at normal atmospheric temperature, the duration of such test being sufficient to determine absolutely that the carrying capacity of the fuse is that at which it is rated. The operation of the fuse under conditions of overload is then determined, starting with comparatively small overloads from 25% up to several hundred per cent., the current being adjusted previously to a definite value, with a fuse in shunt, and the overload being then suddenly thrown upon the fuse. Finally, the operation of the fuse under short-circuit conditions, precisely the same as those that we have to meet in practice, concludes the test on that particular type.

We, moreover, carefully avoid testing a fuse which is intended for use on 110 or 250-volt service on a circuit of either higher or lower potential, which same applies to all the fuses that we manufacture. This, I believe, you will agree with me is a reasonable and accurate method of determination, and the results of the operation of our fuses in practice have certainly sustained us in this position.

The limiting conditions, in my opinion, of this enclosed type of fuse are a matter more of cost than anything else, since with increased capacity comes an increase of cost, which is by no means proportional.

I feel that Mr. Sachs has fallen into the same mistake in his comparative test, referred to on page 158. He has attempted to make comparison between the solid-packed type of fuse and one of our type, without knowing definitely that they were designed to meet the same conditions. Such a test is obviously at fault, and the only way in which determinations can be made, which would definitely answer this question, would be by comparing fuses which were intended to meet some particular condition or class of service.

This statement of Mr. Sachs is on the same line of reasoning as is his comparison of the short-circuit test of the 2500-volt alternating and the 500-volt direct current generators. He has stated in this discussion that he intended to use the term "lagging of the current-rush" to mean diminution of the energy.

I fail to see wherein the word "lagging" can be usedto mean diminution, and in the case referred to the results were unquestionably brought about not by a lagging of the current, but by an actual decrease in the current, due, as Mr. Steinmetz has so clearly pointed out, to the actual momentary wiping out of the voltage across the circuit, conditions which were clearly defined by experiments, which I have referred to before to-night.

I have given a great deal of study to both the solid-packed and the air-drum type of fuse, and my observations have all shown that a degree of sensitiveness and accuracy can be secured in the air-drum type that cannot be approached by *any* form of the solid-packed type of fuse, and, moreover, these tests can be substantiated at any time.

Providence, March 31, 1900.

[COMMUNICATED AFTER ADJOURNMENT BY THE AUTHOR.]

In reply to communications of Messrs. Sargent and Downes.

I believe, in justice to myself, that a few final remarks answering those communicated by Messrs. Sargent and Downes, may be warranted, in view of the premises taken by both of these gentlemen. Mr. Sargent states that it would seem to him "that the enclosed fuse has a large field for 250-volt, or 500-volt work, up to 50 amperes. * * * for larger work, especially station work it would seem from the discussion and remarks of central station men present, that the field for the enclosed fuse would be very small, on account of the cost, bulk, and uncertainty of operation."

If the gentleman had taken the trouble to inform himself more fully in regard to the actual service being performed by fuses of my design, not only in ratings up to 50 amperes, but in current capacities up to 600 amperes, and above, he would probably change his opinion as to the practicability of large fuses of this type. The matter of cost is governed entirely by the character of the service performed, and the necessity for such service.

On the question of bulk, Mr. Sargent certainly cannot say that a fuse capable of running continuously at 600 amperes on 500 volts and operating without arc under any excess current condition, and with a maintenance of its accuracy, is a bulky device when the completed fuse tube with its terminals measures only two and one-half inches in diameter by ten inches long. An 800-ampere fuse for 500-volt services is only three inches in diameter and about ten inches long. If Mr. Sargent will kindly refer to the table in the latter portion of my paper, he will find that a complete list of dimensions is given of the various sizes of fuses.

Why the enclosed fuse should be accused of uncertainty of action in view of the statements made in my paper, and the vast number of these devices in daily use, I cannot understand. Mr. Sargent has absolutely no reason for any such statements. If he has tested fuses of my design he has probably tested them under conditions for which they were not intended. I can but again repeat that enclosed fuses can be built to do all that Mr. Sargent reasonably desires without any uncertainty of operation, and that I stand ready to furnish him with such fuses.

The objection made to enclosed fuses, based on the fact that fuses of different current ratings, and for use on different voltages would require different tube diameters and lengths, is a very old one, and scarcely can be considered as a very weighty one. One might as well say that owing to the different arrangement of circuits, and the different conditions and voltages at which they operate, a large variety of wire sizes must be kept in stock by the supply house, but it would be very much better if the supply house, simply kept one size in stock. I hardly believe that this arrangement would meet the approval of Mr. Sargent, although it is practically analogous to the fuse case.

It is scarcely necessary to again take up the action of the indicator wire, as this has been very fully considered in the paper. Mr. Sargent is, however, entirely incorrect in his assumption that the shunt fuse (the indicator) "practically aids in rupturing the arc, and also forms a menace to any inflammable material near the cutout." The indicator wire does not rupture until the resistance of the interior fuse has been increased, due to its disruption, to a point where the conductivity of the two paths—that is, the interior wire and the exterior indicator,—are almost equal. Then the current, passing through the shunt fuse, is sufficient to rupture it, or perhaps even before this condition is arrived at. The indicator wire then ruptures almost instantly, but the interior wire is still not absolutely ruptured and, as has been stated in the paper, the final break occurs inside of the tube, and not outside. I can scarcely see why Mr. Sargent should at all doubt this, after having seen the experiments and read my paper.

I would request that Mr. Sargent, however, should read the discussion, both at New York and Chicago, and probably obtain some further idea of the action of this indicator. I can only say to Mr. Sargent in regard to the ignition of inflammable material by the indicator wire, that the test made at the Chicago meeting, and mentioned in the Chicago discussion will probably do much to clear this point in his mind. The placing of vents at the end of fuse tubes is not for the purpose of permitting an arc display at these ends, but is simply intended to act as an outlet for some of the excess gases which cannot be taken care of in combination. To question whether the enclosed fuses are as bad in certain ways as the open type is scarcely worthy of serious consideration.

I am pleased to see that Mr. Downes agrees with me in the position that I have taken in building enclosed fuses to meet conditions of electrical service. My experience has clearly demonstrated that this is the correct basis. The matter has been so well discussed that nothing further is needed to establish the fact that a fuse constructed to operate satisfactorily on a trolley car, is not necessarily a poor fuse because it does not operate as well when short-circuited at the bus-bars with 10,000 or 20,000 K. W. in back of it.

I must also agree with Mr. Downes in saying that the limiting conditions governing the operation of enclosed fuses is the matter of cost, which, in the very large sizes, rises disproportionately.

I will not discuss in detail the matter of comparative tests between the solid packed type of fuse of my construction, and the air-space type any more than to say that the record of the tests shown in the paper clearly demonstrates that the matter of hot and cold overload time ratio is in both fuses governed by the same general features.

Finally, I must again take exception to Mr. Downes' statement, "that a degree of sensitiveness and accuracy can be secured in the air drum type that cannot be approached by any form of the solid packed type of fuse, and moreover these tests can be substantiated at any time." I regret to say that the substantiation of such comparative tests is a matter which I am only too eager to do all within my power to bring to a definite head; but have in the past found no reciprocation of this desire. I have not been able to find any air-space fuse that was not beset with all the peculiar features of the solid packed type, and in addition, a number of others which made it by all means inferior to the construction of my design, in which the air-space is entirely omitted. Mr. Downes will find me decidedly agreeable whenever he is ready, to demonstrate the comparative merits of air drum and solid packed fuses, further and beyond the matter already included in my paper.

Discussion at Chicago, April 27th, 1900.

The Chairman (Mr. R. H. Pierce):—Gentlemen, I am sure we feel that Mr. Sachs has conferred a favor upon all of us who are interested in this subject by the able presentation of his paper, and that his practical demonstrations have been most interesting and instructive.

We have a number of gentlemen here this evening who are interested in this subject and who have carried on experiments, and some of them possibly have theories to advance.

We would like to hear from Professor Jackson.

Prof. D. C. Jackson:—Gentlemen, I was not aware when I came to town that there was a meeting of this kind on hand. I want to say, however, that the society is to be congratulated on having Mr. Sachs' paper presented to it. It is evident that Mr. Sachs has eliminated the ordinary errors of experiment with respect to fuses in carrying on his work. I have not carried on a great many experiments in the laboratory with respect to fuses, though I have had a good deal of experience with their use in circuits. Several years ago I was, however, called upon by a manufacturer to give an opinion with regard to a certain fuse alloy, especially with respect to certain points. I made a test of the alloy and gave my opinion, which was rather different from the opinion which was held with respect to similar alloys by many other people, and rather different from the results that had been presented in some papers that might be considered authoritative. I thus became somewhat interested in the matter, and at the time took advantage of the fact that one of my students was about to choose a subject for his "graduating thesis." He was a very reliable young man, with keen intellect and considerable initiative, and I persuaded him to undertake an investigation of certain features of fuse wires. His results are briefly presented in vol. xi, p. 430, of the INSTITUTE TRANSACTIONS.

In the process of doing this he looked up the basis of a great deal of the literature and brought it to my attention in a way that I perhaps would never have undertaken myself, and he found that a good deal of our literature up to that time was in error, due to the fact that the errors of experiment had not been avoided; as, for instance, a great deal of the experimenting which had been carried on with respect to the change of resistance of the fuse when in use or the change of melting point of the fuse when in use—and when I say melting point I mean with respect to the amount of current carried—was replete with errors. These errors were due to the fact that the environment of the fuses under test had not been taken into account. Consequently, in a few hours a fuse might appear to show a higher resistance than its initial value or perhaps the fuse would melt at a lower current than appeared to be sufficient to melt it under similar conditions at first. But these apparent changes were false and were due largely to the effects of the environment, which had not been eliminated. You will find that some authoritative papers of a few years since are all in error on these grounds. I think Mr. Sachs has appreciated the errors of experiment and produced a successful result partially because he has eliminated those errors.

THE CHAIRMAN:—We have with us Mr. Varney, whose experience in the laboratory of the Chicago Board of Underwriters has undoubtedly brought him in contact with the recent developments in this art. We would be pleased to hear from him.

MR. T. VARNEY:—I think it would be well to explain that we have another gentleman present to-night who has done that work, and he would be much better able to discuss his results in that direction than I. Mr. Glover, of the laboratory, has, I believe, conducted a considerable investigation of the fuse, and I think he would be better able to tell you about that than I would. The work that I have had to do has been more especially inspection work in the towns of the central states. In the small towns they are hardly educated yet to the point of enclosed fuses, but I venture to say if they were, it would result in a very material decrease in the fire risk. In many of the small towns they have some crude types of fuse, in some instances perhaps wooden fuse plugs and things of that sort. Undoubtedly this would be a great improvement over most of the fuses in use.

MR. B. H. GLOVER:—Mr. Chairman, I appreciate very greatly the privilege of being here this evening and the privilege of having the floor. This paper has been one of great interest to me, because the subject of fuses has been brought to my attention in so many different forms and under different conditions that I am glad to know of a device which apparently has overcome most of the defects inherent in fuse devices.

There are one or two points that I noted in this paper which I would like to speak about. One very important point mentioned on page 156 is that in the manufacture of these fuses every effort was made to determine the accuracy and reliability of the fuse by actual test. I find that it is a great fault with the manufacturer that he does not fully understand perhaps his own product. For instance, I know of a manufacturer who has no electric current in his factory, and in making fuse plugs or rheostats, if he ever makes a test, he has to put a number in his pocket and go three or four miles to the village electric light plant and connect up with the station meters and possibly get some results.

The position of the underwriter at the present is, if possible, to do away with the use of the varied forms of open link cut-outs. They have proved their unreliability, but perhaps have served their purpose well in bringing the electrical engineer to a position where he can appreciate the necessity for a more perfect device. The introduction of the enclosed fuse from the standpoint of the fire underwriter must be encouraging and gratifying. The effort should be made, if possible, to standardize these devices, and in conversation with Mr. Sachs I was very much pleased to find that he had adopted the same length, I believe, and space-distances, with his fuses and bases as have been already introduced by some of the other manufacturers of enclosed fuses. If a standard can be outlined for these devices, the various manufacturers can then use their ingenuity and wisdom in perfecting the details of the device. I note that with some of these bases it is possible for the fuse to jar or slide out of position, which is a slight mechanical defect which could be very readily remedied and would make the device more reliable perhaps under the various conditions it is liable to meet with in service.

There are one or two questions that I would like to ask, if I may have the privilege, as to the possible effect of the shunt wire indicating device, especially on the smaller fuses; whether the rating of the fuse takes into consideration the very slight, but perhaps appreciable, carrying capacity of this shunt wire? And also, as to the compounding of the active environment, whether it is possible under certain conditions to have this environment separate out so that the active material would not be brought into active connection with the whole fuse wire?

Mr. Sachs:—In answering Professor Jackson first, I do not want by any means to have it considered that this concludes the discussion, because I hope it does not. I must say that amongst the literature on fuses, that the paper to which Professor Jackson referred is one of the shining lights, because it seemed to have first brought out the feature that the professor mentions, namely, the fact that the fuse for its accuracy and for its action almost entirely depends upon the environment. Now, by environment I not only mean the material itself, but the character and the form and also the condition of the environment. I must, however, also add that while this paper possesses peculiar merit on that issue alone, and even if it possessed none other it would be striking in view of the fact that so many writers on the question of fuses have not sufficiently grasped the subject at all.

In general electrical practice fuses have been regarded more as a necessary makeshift than as an accurate, safe and reliable protective appliance. Wiremen and others, who handle these devices, have used them on the basis that if what is required is not at hand, use anything that is, and put it in.

Now, in taking up the question of the fuse protective device from an engineering standpoint, and endeavoring to attack the problem from an actually scientific basis, it may seem that perhaps small fish have been fried. But that is not the fact; because the fuse protective device is a universally applicable and essential apparatus, whose use is increasing instead of decreasing. The demand to-day is for a protective device that shall be safe and accurate. Now, if the old fuse is not, something else must be produced.

Mr. Glover speaks of standardizing the fuse of the enclosed type, and certainly nobody is more desirous of standardization than the manufacturer, for the simple reason that if there is one standard type of receiving device used for the reception of these fuses, why then any one manufacturer can go into any other manufacturer's block and sell fuses where the other fellow previously sold them. Specialization for individual custom is the thorn in the side of economical manufacture. I know that I for one am highly desirous of standardization in this direction. The fact still remains that some fuses are capable of being placed where others cannot be placed; and while it is probably fairly possible to adopt common lengths, it may be essential to vary detail construction in exactly the fashion that Mr. Glover has mentioned.

The condition that Mr. Glover mentions in connection with the jarring of the fuse, refers, I presume, particularly to the snap contact block, in one or two sizes, in which it is possible to shove the fuse lengthwise. That is to be remedied. We have found, however, no objection to the jarring, although a number of these blocks have been in position. It is scarcely possible to sufficiently jar such a cut-out, as ordinarily installed, to produce this condition. The shunt resistance to which Mr. Glover's other inquiry refers is not at all taken into consideration in rating the fuse, owing to the very high resistance of the shunt indicating wire.. I have forgotten the exact resistance of the wire per inch, but it is very high. I believe a six-inch piece measures something like 15 or 20 ohms. You will readily appreciate, therefore, that when such resistance in its proportionate length to the size of the fuse on which it is used is shunted by such extremely low resistance of the high conductivity main fuse, that the current is shunted out of the high-resistance conductor and passes practically entirely through the fuse conductor itself; so that under normal conditions the percentage of current flowing through the indicating conductor is a negligible percentage of the current carried by the complete fuse. In fact, it is not taken into consideration in rating any of these fuses. On very delicate fuses of quite some resistance, where the carrying capacity is a small fraction of an ampere, an indicator wire of the type I have here cannot be used.

It seems rather strange that it was necessary to go through all this experience with arcing fuses before it was actually possible to get the electrical fraternity to appreciate the necessity of a protective device that eliminated the fire hazard. Back in 1890 I had the greatest difficulty in trying to interest people in this device. It could not be done One gentleman said to me, as I often hear to-day, "What is the use of putting the fuse in a tube when it works without a tube?" And I even find to-day that appreciation on the part of the user will come slowly, but I believe when it does it surely will stay.

As Mr. Glover says, the underwriters will necessarily always favor a device that adds to the safety of an electrical installation, and I believe, after the electrical contractor and the user has discovered the fact that it is really cheaper to get rid of this fire hazard and pay a little more money for his fuse, that the enclosed fuse will become universal.

I note that Mr. Cutler is present this evening. Mr. Cutler entered into the discussion about a year or two ago on the enclosed fuse, and I know we would all be pleased to hear from him.

MR. H. H. CUTLER:—Mr. Chairman, I would be glad to say a few words if I can assist matters any. I might start by saying that three years ago, when the enclosed fuses were put on the market in practical shape, I was very much interested in the question. It was just what I had been looking for, and I received it with open arms. I wanted it for a peculiar use. It might be interesting to state what that was. I had been manufacturing, and still am, as most of you know, a device for starting motors, and on a great many of them I put what is generally known as an overload attachment. This overload attachment I have always known was of no earthly use as a circuit-breaker. But most people think to-day that it is a circuit-breaker. It is only of use for normal overload. I wanted something to make a complete device to get on the market with. I had had enough experience to become disgusted with open fuses a good many years ago, and when the enclosed fuse came out I put it on my device and I went so far as to advocate its use in my catalogue. I think it might be interesting to read just what I say about this enclosed fuse in my catalogue. I tore out a page on my way down here. "The prices given on page 21 of our catalogue include the furnishing of a pair of enclosed fuses, rated to blow at a current twice as great as the ampere rating of the motor for which the starting rheostat is furnished. Our overload attachment will satisfactorily protect the motor from abnormal currents up to 50% overload, according to the position at which it is set. Should a short-circuit occur or a very heavy load be suddenly thrown upon the motor, the fuses can be absolutely depended upon to blow. This they will do with absolutely no arcing whatever, thereby constituting a distinct advantage as a fire risk over the use of a circuit-breaker, which draws a long, flaming arc when opening a circuit carrying an abnormal current. The enclosed fuses have no mechanism to get out of order or parts which can be improperly adjusted by uninformed persons. They will not rust or deteriorate, are unaffected by moisture, temperature and other external conditions, and will be found ready to act at any time without requiring the slightest attention. By using these enclosed fuses in connection with our overload attachment, the fuses will never be called upon to act, except in cases of accidental short-circuits. Both the motor and the starting rheostat are as perfectly protected as it is possible to have them."

I thus constituted myself an advertising agent for the manufacture of enclosed fuses, for which I did not get a cent. I am simply doing it in the interests of good engineering, and it helps our apparatus; it helps its reputation. However, you know that most people will not pay anything for it. As a matter of fact, not 10% of our apparatus goes out with enclosed fuses on it, because people won't pay 20 or 40 cents more on a rheostat that costs them all the way from $10 to $50. At the same time, I asked my order clerk to-day on coming in about how much money we were spending for enclosed fuses that we gave away to people, and I found it was costing us about $50 a month to advance this cause of good engineering.

I might say after I adopted it myself I took an agency and wanted to help the thing along, and I tried to introduce them among my acquaintances here in Chicago. One of the first persons I called upon was my friend Pierce here. I showed him one of the fuses, and he said: "It looks like a pretty good thing. Just leave a few and we will try them." That is the last I ever heard of it. That was two years ago. I took them out and showed them to a dozen people and had about the same result. I found that the only way I could get rid of them was to give them away. Nobody would pay for them.

There was one thing I noticed here—the difference between the merits of the solid-packed fuse and the fuse with an air space. Now, from the description which Mr. Sachs gave us I am not clear whether his fuse has an air chamber or not, and I would like to have him answer that. But I noticed that Mr. Sachs himself stated an objection to the solid-packed fuse, namely, that the metal would stay in a melted condition and thereby create an arc. What I have always understood as the advantage of the air space was to prevent this molten metal from allowing the current to continue to flow. It also seemed to me, as I understood the paper, that the reason the solid-packed fuse blew before the fuse with the air chamber was due more to the character of the metal which Mr. Sachs used in his fuse than it was to the existence of the air chamber. That point I am not clear on.

I also noticed another thing, that you have got a very nice name for this fuse, a "no-arc" fuse, but at the same time it does arc. Now, the enclosed fuse possesses the distinguishing advantage of having absolutely no arc, and while in a great many cases, of course, this little arc with the wire is no objection, in some cases it would be, but it destroys the theory of the thing. It is so pretty to say a fuse blows when you don't know it.

Mr. Sachs:—That is just exactly the point, it is too pretty. It is pretty to the extent that you don't know it; but you want to know it.

Mr. Cutler:—Well, I think the indicator might be an advantage, but I think some people wouldn't want it if they were going to use it in a flour mill or anything of that kind.

Mr. Sachs:—You don't have to use the indicator, you know, if you don't want it. The sole use of these fuses is not confined to flour mills or powder magazines.

Mr. Cutler:—No, you don't have to use it. But it is not a "no-arc" fuse with that indicator on.

Mr. Sachs:—If Mr. Cutler will carefully read my paper he will find that the action causing the disruption of the indicator can by no means be considered as resulting in an arc. In order, however, to thoroughly convince Mr. Cutler I will blow several fuses with cotton lint packed around them. I hope Mr. Cutler will at least be partially satisfied with these tests.

Mr. Cutler:—I heard you speak very favorably of the underwriters just now. I think a good deal of the underwriters sometimes, but sometimes I get very much discouraged, which, in the case of these articles that you referred to just now, was due entirely to the obstinacy of the underwriters in New York City. Possibly, very few people knew what made me arrive at this inquiry. It came about by a law that was passed in New York City which required every person who installed a motor to put on a circuit-breaker. I was very much disgusted with that law because I was not making circuit-breakers. It came about through a test started under the auspices of the Edison Illuminating Company, and all the manufacturers exhibited starters in, and an enclosed fuse was suggested at that time. Now, the chief of the Electrical Department was present when this circuit-breaker was presented but took no interest whatever in this enclosed fuse, which acted perfectly; there was no fire risk whatever, and it showed by the test that was made to be more depended upon than any circuit-breaker that was exhibited. Nevertheless, that rule was passed, that it didn't make any difference whether you used an enclosed fuse, the circuit-breaker had to be put on. That is one thing the underwriters do sometimes.

Now, I have always been a strong advocate of fuses, and, as some of you know, I have put them in places where other people think they are worse than useless. For instance, I noticed that you mentioned the fact that the fuse could not be used in the place of circuit-breakers on account of the time taken to replace them. Now, of course, that is very easily overcome by having several fuses with switches to throw them on. I have found also that they can be used on switchboards, and they can be used on railway feeders, provided you get good circuit fuses up to a thousand or more amperes, though up to the present time I have never seen one. But if you got them you would have a very great advantage over the present circuit-breaker that is being used, namely, that nine times out of ten when the circuit-breaker blows it ought not to blow. If you put a fuse in in place of the circuit-breaker it would not blow so often. So that it simmers down to the question of expense of renewing the fuses. If that could be got down cheap enough, I would prefer them to the circuit-breakers.

Another thing you brought up that I noticed was your suggestion of shunting switches to take the arc off. I think that would be considerable of a nuisance.

That brings us to another fact that I would like to state. I have gone on record several times as stating that the open fuse was a relic of the past, and I think also that the ordinary double-pole knife-switch is another and is not going to last. If switches were built properly there would be no need of shunting them with a fuse, and switches are going to be built properly so that they will not only act as switches, but also as circuit-openers, so that they can be quickly opened and closed, no matter whether the current is on or not. That is the thing we have got to have and will have.

MR. SACHS:—I think our chairman is quite familiar with the fuse question, and I think he ought to say something either pro or con.

THE CHAIRMAN:—I will say something in regard to what Mr. Cutler has said here, which might indicate to people who do not know me that I did not appreciate the advantages of a good fuse. In the first place, I have always been strongly in favor of the fuse, and most strongly opposed to the use of circuit-breakers in places where fuses should be used. This applies most commonly to the use of circuit-breakers on incandescent circuits. One example is enough. The other day in going over a plant which was originally designed by other people, but which we are at present completing, I found that they had circuit-breakers controlling the generators on an ordinary lighting circuit, and that the circuit-breaker would go out before it would blow a sixty-light fuse, the circuit-breaker being put in to protect a direct-current hundred-kilowatt machine. I think that one illustration is enough to show the foolishness of this indiscriminate use of circuit-breakers, due to the eloquence of the gentlemen who are selling them.

In regard to my seeming indifference to the enclosed fuse, I will say that that was probably due to the feeble efforts of the salesman. This may be excused possibly by the fact that there was "nothing in it," as he has explained. Shortly after seeing the enclosed fuse, which, as the gentleman says, I approved in a general way, I set myself about to design a switchboard in a plant where this could be used. I don't mean to say that I was going to design a plant just to work this fuse in, but I had a place where they would go if they were all right. I found that the makers had a fuse which would do all right where it controlled but a small amount of energy, *i. e.*, for a low-voltage, small current which was already cared for pretty well by the Edison plug,(which was approved by the underwriters.) but I found when it came to getting anything for higher potentials and large currents, that, in the first place, I couldn't get them at all: and, in the second place, there seemed to be no standard adopted; and, in the third place, I got very meager information as to what the people who were building these fuses could produce. So that possibly my trouble was not due to any deficiency of the salesmen, who probably had met these same difficulties, and therefore did not come back to me, but was due to the fact that this matter had not been taken up in the same scientific and thorough manner in which Mr. Sachs has taken it up. In other words, the enclosed fuse was not at that time developed; and I will say that the last attempt that I made to get a large fuse was a failure.

In laying out a plant it is necessary for an engineer to have at hand some practical data of sizes and dimensions. You can't lay out a switchboard and then trust to luck to find fuses to fit the switchboard and terminals. If you do, you will have to make the switchboard over, and there will be an extra expense for that. I think it is very safe to say that as soon as these fuses are reduced to a standard they will immediately be adopted by the engineers for all cases which have been covered by the manufacturer.

In regard to Mr. Cutler's conclusion on switches I will say that I was very much interested in the ideas set forth on page 161 of using a fuse something like this to shunt a switch, because if it is possible to use a fuse that will handle voltages which Mr. Sachs says he can handle, it seems to be a satisfactory way of doing something which I have not yet seen done satisfactorily—that is, the breaking of circuits of very high potential. Any remarks about switches used for this purpose might be considered a criticism on the manufacturers and might be inopportune, as these switches are in the development stage. But I can see how this use of the fuse may be very desirable in certain cases, and I hope that Mr. Sachs will at some time in the future give us information that will enable us to know what we can do with these fuses.

In regard to the question that Mr. Cutler raised about opening circuits with switches I notice that the recent writers on this subject have drawn a distinction. I don't remember the exact wording, but I think it is between what they call "circuit-openers" and "current-openers"—that is, between a device which shall break the current and one which shall open the circuit. In a great many cases it is very desirable to have a device which will open the circuit when there is no current on, which can be done very cheaply. Where we have very high voltage feeders it becomes very expensive to go into the extremely complicated and costly switches for opening these circuits while carrying current, and ordinarily these circuits do not have to be opened with great frequency, and in many cases the ordinary switch is all right. The fuse such as has been described here, if used in very high voltage circuits, gives us a means of opening the circuits occasionally and under abnormal conditions when we are compelled to use a switch or some device as a current-opener.

Mr. Cutler:—I would like to say a few more words about the position which I took in not advocating the fuse for a switch. The greatest objection to it is that it is not "fool-proof." You can't get a man, after he has opened that switch once, to renew the fuse. That is the greatest point which manufacturers of electrical apparatus have to contend with—to make their appliances "fool-proof." You have got to make it not only so that it will work, but so that it is bound to work under any conditions.

I was reading an article to-night in which it was stated that the rule of writing correctly was to write in such a way, not that it could be understood, but so that it could not be misunderstood. That applies to making machinery. It is all right theoretically, of course; it stops the arcing.

Now, in regard to what I said about knife switches, it is not expensive to make knife switches properly; in fact, it is not as expensive as the way they make knife switches now. I allude to what is known as the clip type. It is very expensive to make a first-class clip switch. Switches that you buy have three or four clips on them, and they will touch on the edges of one or two and the others won't touch. To make a good one you have got to grind them to make a perfect contact. The ideal way to make a switch is to use laminated copper leaves and tip them with carbon, so that the laminated leaves leave before the carbon does. It is a very cheap switch to make. I have built thousands of them and I have never had one complaint, and you get no burning whatsoever on the copper contact. All the arcing is on the carbon. Now, you can open just as big a circuit, just as big a current with that sort of switch as you can with the circuit-breaker. That switch will not cost as much money to build as the switches that are on the market to-day.

There are those two objections then to putting a fuse across a switch, that it is not "fool-proof" and it is not necessary, and it saves no money, in my opinion.

THE CHAIRMAN:—I would like to say in regard to the use of switches for current-breaking that there is no discussion between Mr. Cutler and myself, because I take the same position. The ordinary switch is unsuitable for breaking current where the switches carry a large amount of energy. If we could get a switch that is made as good as the circuit-breaker and get it for less money, that is something we would be very glad to get, I am sure. I am glad to receive that information as well as what I have learned about the fuse.

I am strongly in favor of making everything "fool-proof," and I have struggled hard to spend money for that purpose in some cases, and I don't see that a fuse in connection with the switch would be of universal application. What I suggest is that it might be a very good thing in these special cases of extremely high voltages. These extremely high voltages are usually employed only in long-distance transmission from central stations, which central stations require the attendance of intelligent and experienced men; and while it is probably absolutely necessary to make an isolated plant "fool-proof" from one end to another as far as possible, to do that is practically impossible in a large central station, and there is a limit to what can be spent for installation. It is probably cheaper in a large station sometimes to pay for a little better grade of man than it is to pay for a very much higher grade of complicated apparatus.

MR. SACHS:—Mr. Chairman, I wish to answer Mr. Cutler's discussion of my paper, and I want to begin that answer with an almost complete exoneration of the underwriters.

I have had quite some experience with the underwriters, and have also been directly connected with one of the municipal boards. Mr. Cutler has labored under a slight misconception—perhaps it would be better to say he has applied a misnomer to the board that acted upon the matter of motor protection in New York, where I resided up to about a year ago.

Mr. Cutler:—That is right; it was not the underwriters.

Mr. Sachs:—It was not the underwriters by any means. In fact, the underwriters were entirely rational in the matter. But it was the Municipal Inspection Board that made this peculiar ruling. The underwriters by no means wanted a circuit-breaker installed with every motor.

I wish to explain to Mr. Cutler the difference between a solid-packed enclosed fuse and an air chamber fuse. I have named my fuse generally the solid-packed fuse in the course of the paper, which Mr. Cutler only saw this evening, and hence has not fully perused, or he might know that I speak of two types of solid-packed fuses. The mere packing of a tube and the throwing into that tube of chalk or sand or flue dust or anything that you can lay your hands on does not make an enclosed fuse that is accurate or safe, and such an enclosed fuse has the peculiar characteristics that Mr. Cutler mentioned, namely, that it is not accurate and it is not safe, for the simple reason as mentioned on page 141 and against the bottom of page 139. Mr. Cutler will find on page 141, for instance, the record of a test of an "X" solid-packed fuse. This is a fuse with chalk thrown into the tube. Such a fuse as this, with the wire in a molten condition, is absolutely inaccurate. And he will also find by continuing on in the paper that it fully discusses the matter of surrounding the wire with a material that eliminates this peculiar hanging, and this material requires the most careful selection, but by the use of such material, which completely surrounds the fuse wire and fills the casing between the wire and the sides of the casing completely, we also obtain a vast multitude of advantages over the air chamber fuse.

In the first place it must be remembered that any fuse surrounded by air always retains some of the disadvantages of an air-surrounded fuse as far as accuracy is concerned, although to a very great extent it may be practically safe.

The detrimental results of oxide formations around the air-surrounded fuse wire in either case greatly affect the operative accuracy of the device in time. Aside from this feature, the absorption of at least some, if not all, of the gases of disruption in forming a combination with the filling is unquestionably capable of better results than when these gases can only be destroyed by parting with their heat in passing through the interstices of the filling. The amount of metal dissipated is also an important item. These points are fully discussed in the paper.

The fuse that I have devised is a solid-packed fuse, which type, I claim, is superior to any other, as it contains the minimum amount of air, it absorbs some of this disruptive energy—I don't say all, but some—it is absolutely accurate and cannot fail to operate when overloaded. Owing to the fluxing action of the filling on the wire surface it is impossible for the fuse to continuously carry more current than it is designed for.

The matter of the indicating wire being in its action contrary to the name of the fuse, I beg most strongly to take exception to, for the simple reason that, as I have shown you, the indicating wire does not arc, it is simply melted, the break being really shunted by the final interior break. To prove this I will try the experiment previously mentioned.

[Mr. Sachs here placed dry cotton waste upon an enclosed fuse and blew it without setting fire to the waste.]

Perhaps that will satisfy Mr. Cutler. Mr. Cutler must remember that an arc and a mere melting are two different things. What we are getting there is really a melting of the indicator with perhaps a slight spark. I seriously doubt that there is any material, except gunpowder, or perhaps acetylene, illuminating or other highly inflammable gas, that if brought in direct contact with that little spark would actually be ignited by it. But, aside from that, it is true that the fuse has an indicator, but if Mr. Cutler finds this feature undesirable, it can be gotten rid of very easily. All you have got to do is to take your penknife and cut it off. Now, if Mr. Cutler would rather use fuses without indicators, he is entitled to do so. But I shall not charge any more for the fuse with or without an indicator. I am a firm believer in the precept that you should always know what you are about before going ahead. You can't go ahead until you know whether your fuse has blown or not. If you have an indicator to show that it has blown, all guesswork and risk is eliminated. We have had a number of cases brought to our attention in which the enclosed fuses were to blame for serious results, simply because they had no means of notifying the user when they were disrupted.

In the matter of fuses on switchboards in place of circuit-breakers, I agree with Mr. Cutler most heartily; and the use of a fuse that can be thrown into the circuit as quickly as a circuit-breaker is an entirely reasonable device. I have a fuse of this type under consideration, consisting of a magazine fuse device that can be mounted upon a switchboard with a handle to project the same as a rheostat handle projects. All that is necessary is to turn the handle. The turning of the handle can even be performed automatically when the fuse is used as a circuit-breaker.

In regard to shunting switch breaks on medium or high-potentail circuits, I think the view taken by Mr. Pierce is entirely the correct one. You don't have to shunt a break on a 220-volt switch, and perhaps you don't have to shunt a break on a 500-volt switch; but when it comes to breaking currents on 2500 volts or above, why, it becomes necessary to provide some medium to eliminate arcing, because even the slightest tendency to create a conducting medium between your breaking points starts an arc which under these potentials is severely destructive. In the fuse-shunted breaks the starting of an arc at the switch is eliminated. I, by no means, recommend such a device for use where the switches are opened and closed many times an hour—it would be rather an expensive switch to use; one for which you would pay 12 cents, 15 or 20 cents or more than that every time you opened it. For the satisfactory operation of this arrangement it necessarily follows that every time you open the switch there is load enough on it to blow the fuse, which has a much smaller capacity than the switch, and the placing of a new switch must be assured.

On the "fool-proof" question, I must say that I also take exactly Mr. Pierce's view. You can't build a thing absolutely "fool-proof," and when you are putting in thousands and thousands of dollars worth of machinery, certainly you should not put a dollar-and-a-half-a-day man in charge of it. When you find that your three-dollar-a-day man hasn't got brains enough to operate the switch properly you get rid of the man and not the switch.

I stand ready to-day to say that an enclosed switch fuse of this character can be produced to rupture almost any excess-current condition. It is surely a question of a proper combination of wire and casing and filling. Certainly when you get enormous potentials or enormous current capacities, your fuse may perhaps be abnormally large, but the circuit can be ruptured without arcing if the fuse is properly constructed. I have built fuses large enough to demonstrate that. In fact, have opened a short-circuit on one of the largest street railway systems in the world, the fuse having a normal current-carrying capacity continuously of about 500 K.W., which is by no means small.

I think that owing to the fact that this paper was probably not in the hands of a great many present, and as Mr. Cutler only received it to-night that it has made it a little difficult probably for him to discuss it as fully as he would like; and as we all appreciate that written communications are in order, I think that any further discussion might be conducted in writing.

[Adjourned.]

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, April 25th, 1900.

The 142d meeting was held at 12 West 31st Street, this date, and was called to order at 8:35 P. M. by Manager Steinmetz.

THE CHAIRMAN:—The meeting is called to order. I give the floor to the Secretary to make some announcements.

SECRETARY POPE:—At the meeting of the Executive Committee this afternoon the following associate members were elected:

BARR, JOHN B.	Electrical Engineer General Electric Co., residence 234 Union Street, Schenectady, N. Y.	C P. Steinmetz. Ernest Berg. A. H. Armstrong.
BROWNE, WM. HAND, JR.	Asst. Professor of Electrical Engineering, The University of Illinois, Urbana, Ill.	R. B. Owens. Wm. Esty. Wm. S. Aldrich.
COLE, WM. HOWARD	Engineer, Ferrocarriles del Districto Federal, Mexico City, Mexico.	C. F. Beames. A. E. Worswick. P. H. Evans.
GUERRERO, JULIO	Associated with the Durango Electric Light Co., Victoria, 12 Durango, Mex.	C. F. Beames. P. H. Evans. M. T. Thompson.
GUTIERREZ, MANUEL R.	Professor of Physics, Normal School, Jalapa, Mexico.	M. T. Thompson. P. H. Evans. C. F. Beames.
HANSCOM, WM. W.	Chief Electrical Engineer, Union Iron Works, 612 O'Farrell Street, San Francisco, Cala.	F. F. Barbour. H. A. Russell. J. A. Lighthipe.
LEAMY, J. M.	Electrician, Dominion Government, 250 Lyon St., Ottawa, Canada.	T. Ahearn. A. A. Dion. Ralph W. Pope.
LIVSEY, J. H.	Salesman and Manager Detroit Office General Electric Company, 704 Chamber of Commerce, Detroit, Mich.	W. L. R. Emmet. Alex Dow. A. F. Walker.
MARSHALL, CLOYD	Designer of Electrical Machinery, Jenney Elec. M'f'g, Co., Indianapolis, Ind.	Harold B. Smith. W.E.Goldsbor'gh. C. P. Matthews.

McClure, William J.	Associated with H. D. Brown, Electrical Engineers and Contractors, residence, 259 West 52nd Street, New York City.	W. H. Ripley. F. B. Crocker. M. I. Pupin.
Moore, John Peabody	Tester, General Electric Co., P. O. Box 389, Schenectady, N. Y.	A. F. McKissick. R. W. Pope. W. E. Boileau.
Oolgaardt, J. J.	Electrical Engineer, (Foreign Dept.) General Electric Co., residence, Edison Hotel, Schenectady, N. Y.	Ernst Berg. C. P. Steinmetz. A. L. Rohrer.
Osborne, Marshall	Engineer in charge of Contracts, The British Thomson-Houston Co., 83 Cannon St., London, Eng.	H. F. Parshall. H. M. Hobart. Ralph W. Pope.
Slichter, Walter I.	Electrical Engineer, General Electric Co., residence, 234 Union St., Schenectady, N.Y.	C. P. Steinmetz. Ernst Berg. A. H. Armstrong.
Somellera, Gabriel F.	Partner, Salcedo & Co., Apartado 115, Mexico City, Mexico.	C. F. Beames. J. H. Shearer. P. H. Evans.
Steele, Walter D.	Electrical Engineer Public Light Commission, The City of Detroit, 40 Atwater St., E. Detroit, Mich.	Alex Dow. E. P. Warner. Jesse M. Smith.
Varley, Richard Jr.,	President, the Varley Duplex Magnet Co., 188 7th Street, Jersey City, residence, Englewood, N. J.	Townsend Wolcott E. A. Colby. H. Laws Webb.
de Waal Wm. H.	Engineer, Accumulator M'f'g Co., Cadena, No. 8, Mexico City, Mexico.	C. F. Beames. P. H. Evans. M. T. Thompson.

The following associate members were transferred to full membership:

Approved by Board of Examiners, March 9th, 1900.

William S. Aldrich	Professor of Electrical Engineering, University of Illinois, Urbana, Ill.
Harold B. Smith	Professor of Electrical Engineering, Worcester Polytechnic Institute, Worcester, Mass.

The Chairman:—It is very encouraging to see the growth of the Institute and note the spreading of its membership, not only through the United States, but even in the foreign countries of both hemispheres.

The next topic in order is the reading of a paper on "Hysteresis in Sheet Iron and Steel," by Arthur Hillyer Ford, to whom I give the floor.

A paper presented at the 142nd Meeting of the American Institute of Electrical Engineers, New York, April 25th, 1900. Manager Steinmetz in the Chair.

HYSTERESIS IN SHEET IRON AND STEEL.

BY ARTHUR HILLYER FORD.

Since the general introduction of stations for the supply of light and power, by the use of alternating currents, the subject of hysteresis loss in iron has been an important study from the standpoint of the efficiency of such installations. In the direct current system the only place where hysteresis loss occurs is in the armatures of the dynamos and motors; while the alternating current system has in addition the loss in transformer cores, which is apt to be larger than all other electrical losses combined, in the case of a station operating 24 hours per day. Therefore a slight increase in this loss may make a decided difference in the efficiency. Take as an example a two K.W. transformer having a copper loss of 56 watts and an iron loss of 42 watts which gives a maximum efficiency of 95.2% and an all-day efficiency of 86.7% on a basis of full load for four hours and the remainder of the time no load. If the iron loss is increased 20% the efficiencies become 95.0% and 84.8%

During the latter part of 1894, attention was called to the fact that there is an increase in the core loss (hysteresis and eddy current) of a transformer, or that the iron aged with use, in a letter by G. W. Partridge[1] to the *London Electrician*. This called forth a communication from J. A. Fleming,[2] citing similar observations which had been made in 1892. This aging was first

---

1. "Increase of Open Circuit Loss in Transformers with Time." *Electrician* (London) Vol. 34, p. 161.

2. "Time Increase of the Open Circuit Loss in Transformers." *Ibid*, Vol. 34, p. 190.

thought to be due to magnetic fatigue, but is has been shown by O. T. Blathy,[3] W. M. Mordey,[4] J. A. Ewing,[5] and others to be purely a heat effect.

The method used by Ewing was to subject the iron to rapid reversals of magnetism, at the same time keeping it cool, when no increase of the hysteresis loss was noticed. That used by Mordey was to make two cores from the same sample of iron and heat one to a given temperature by magnetic reversals and the other to the same temperature from some external source. On measuring the hysteresis loss it was found to increase at the same rate in both cores, thus showing that this increase is a pure heat effect. This method has been used by others, who took iron cores and found no aging when they were subjected to an alternating magnetic field and kept cool, but on allowing them to get hot, there was an immediate increase in the hysteresis loss.

Up to the present time there have been no tests published which throw any light on the cause of the increase of this loss.

This research was undertaken for the purpose of discovering if possible what the cause of this effect is, in order to find how it may be reduced. That it may be reduced seems probable to everyone who has studied the subject, for there are some irons which show this effect very slightly. Experiments have been carried out in a similar direction by F. Guilbert[6] which tend to show that chemical composition has no appreciable effect on the hysteresis loss in soft sheet iron.

This research is divided into two parts. I.—That on commercial transformers, which was undertaken with the object of showing the magnitude of the aging under conditions met in practice. II.—That on small specimens of iron obtained from various makers and users.

Thanks are extended to the various companies who furnished the iron and transformers for this series of tests and to those who made the chemical analyses.

---

[3] *Electrician* (London), Vol. 34, p. 191.

[4] "On Slow Changes in the Permeability of Iron." *Ibid*, Vol. 34, p. 219.

[5] "Is the Magnetic Quality of Iron Affected by often Repeated Reversals?" *Ibid* Vol. 34, p. 297.

[6] "On the Law of Hysteresis." *L'Eclairage Electrique*, Vol. 6, pp. 357, 390.

I.—Measurement of the Core Losses of Eight Transformers to Show the Magnitude of the Aging Effect.

These transformers were all obtained between June 1894 and October 1896 and had been used none, or for a few hours only, for testing purposes in the laboratory. They were connected with the high pressure coil of one, feeding the high pressure coil of the next, whose low pressure coil fed the low pressure coil of the third, and so on, with a lamp load on the low pressure coil of the last transformers. By requiring the large transformers to supply lamps, in addition to the power for the smaller ones, the load on each was made about two-thirds of its rated capacity and was kept on continuously with the exception of a few hours each week while the station was shut down.

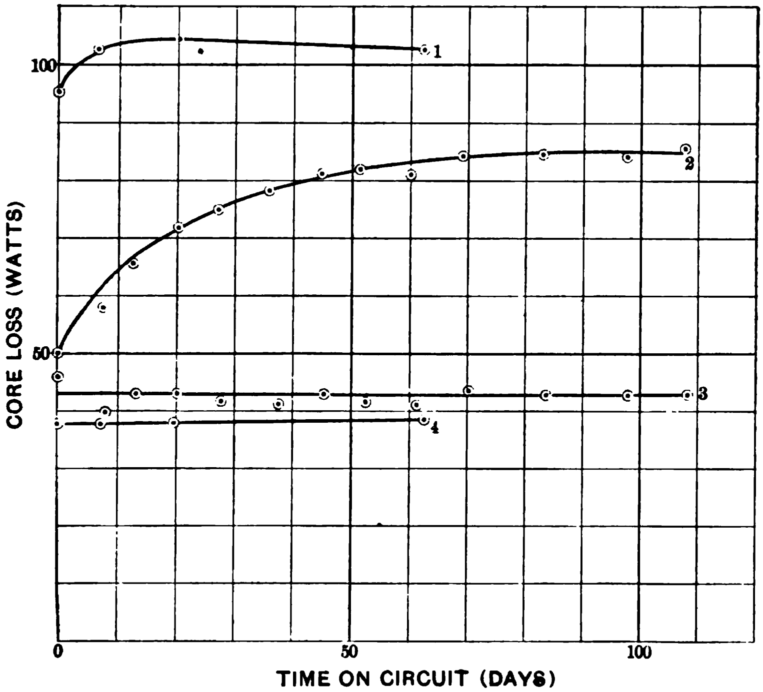


Fig. 1.

The transformer capacities and the increase in the core losses are shown in Table I, and Figs. 1 and 2.

TABLE I.

No.	Capacity.	Increase in Core Loss.
1	1.5 K.W	25%
2	1.5 "	95%
3	1.5 "	2%
4	1.5 "	4%
5	1.25 "	113%
6	2.5 "	88%
7	1.5 "	20%
8	1. "	10%

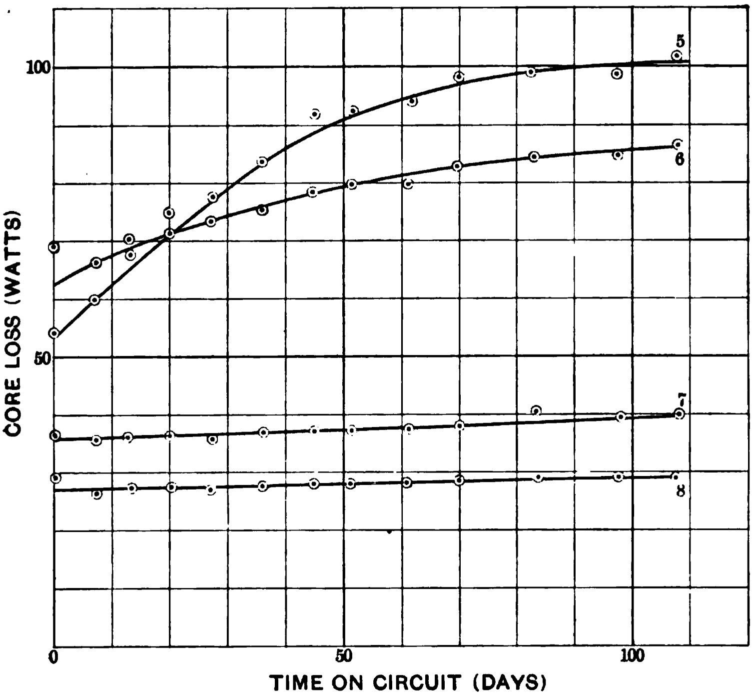


Fig. 2.

The first value of the core loss is high because it was made while the transformers were at the temperature of the room, while the other readings were taken while they were hot. In calculating the increase in the loss, the results of a previous core-loss measurement were used in order to get the total aging; for a slight increase was noticed on account of the use noted previously. It is to be noted that while the increase is in the hysteresis loss, the results are given for the total loss which will make the percentage increase of the hysteresis loss somewhat greater.

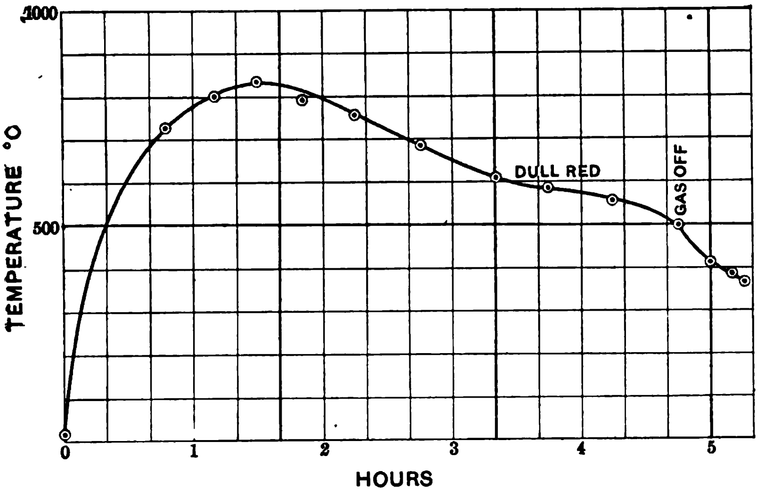

1000
500
TEMPERATURE °C
DULL RED
GAS OFF
0
1
2
3
4
5
HOURS

FIG. 3.

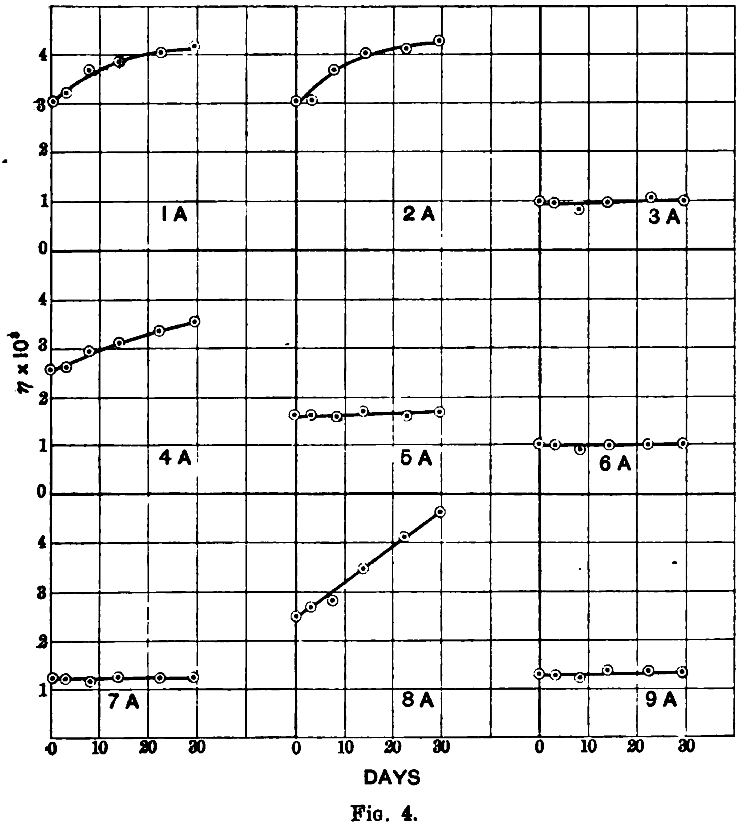

4
3
2
1
0
1 A
2 A
3 A
4 A
5 A
6 A
7 A
8 A
9 A
η x 10³
0
10
20
30
DAYS

FIG. 4.

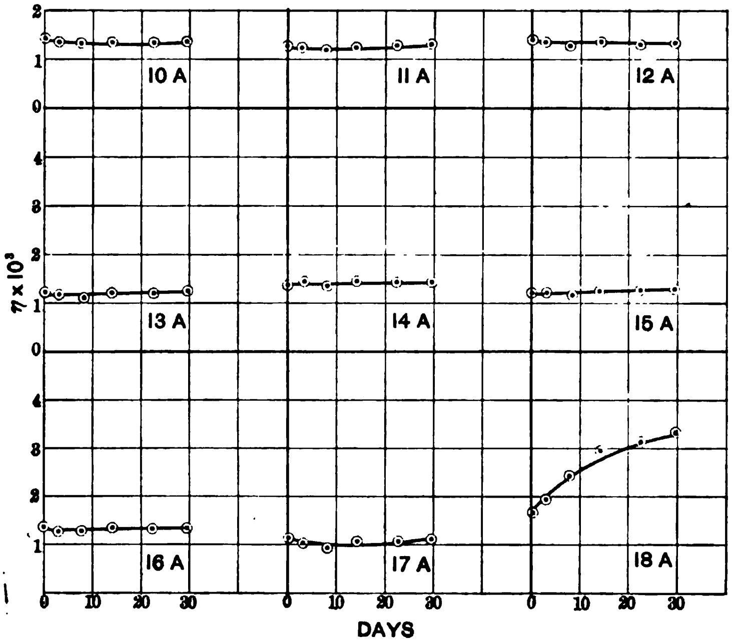

η x 10³
2
1
0
4
3
2
1
0
4
3
2
1
10 A
11 A
12 A
13 A
14 A
15 A
16 A
17 A
18 A
0
10
20
30
DAYS

Fig. 5.

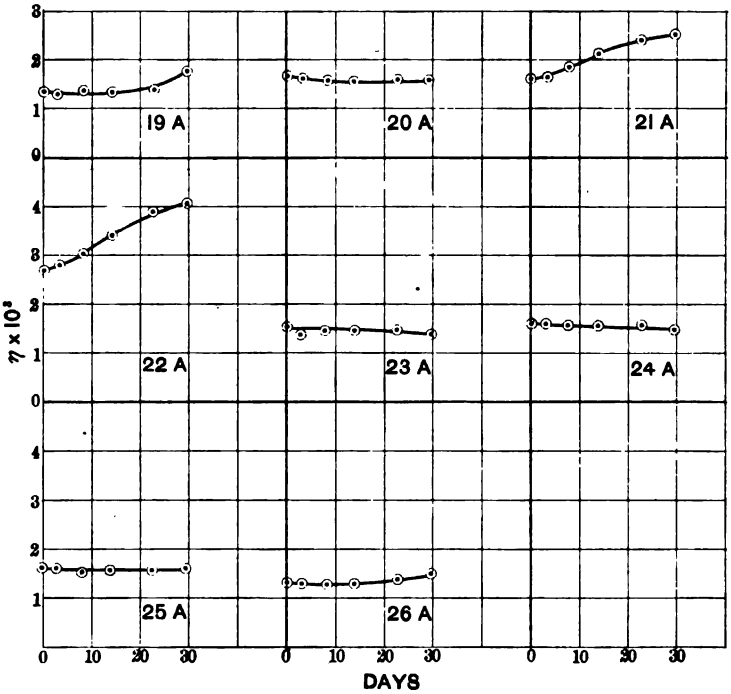

η x 10³
3
2
1
0
4
3
2
1
0
4
3
2
1
19 A
20 A
21 A
22 A
23 A
24 A
25 A
26 A
0
10
20
30
DAYS

Fig. 6.

II.—Test of the Hysteresis Loss of Small Samples.

Heat Treatment.—The samples were subjected to four different heat treatments which will be designated A, B, C, and D throughout this paper. Samples A, B, and C were heated in a gas muffle to a temperature of 835° C. taking 1.5 hours, and then allowed to cool slowly as the muffle cooled, taking 3.75 hours to cool to a temperature of 365° C. when the gas was shut off. Samples D were taken out of the muffle during the heating, when a temperature of 804° C. was reached, and quenched in water at a temperature of about 15° C. Samples B and C were heated with the muffle the next day after being annealed. When a temperature of 205° C. was reached after heating one-half hour, samples B were taken out and quenched. After one hour, when a temperature of 400° C. was reached, samples C were quenched.

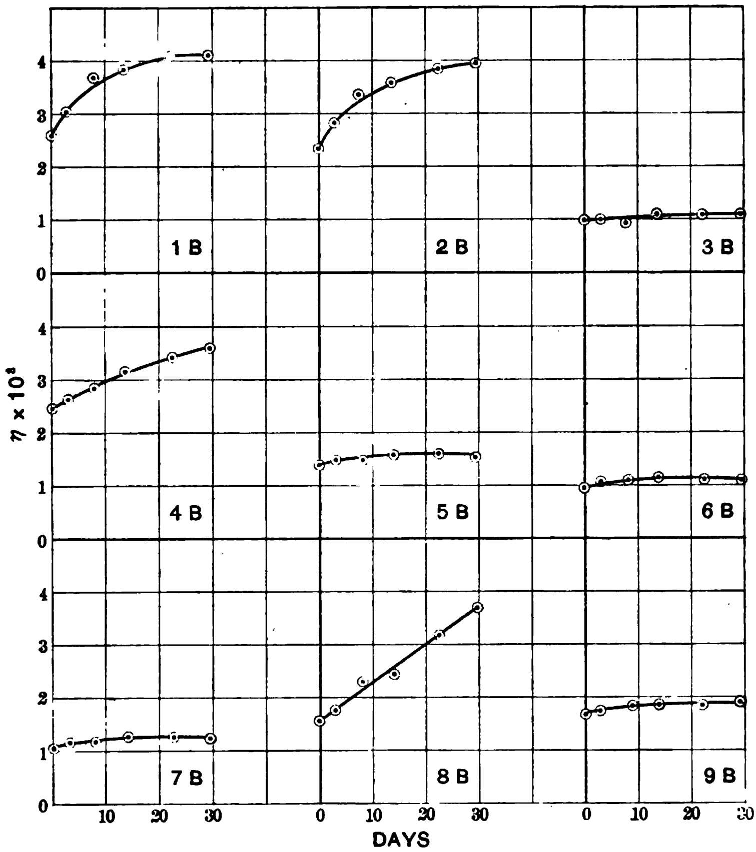


Fig. 7.

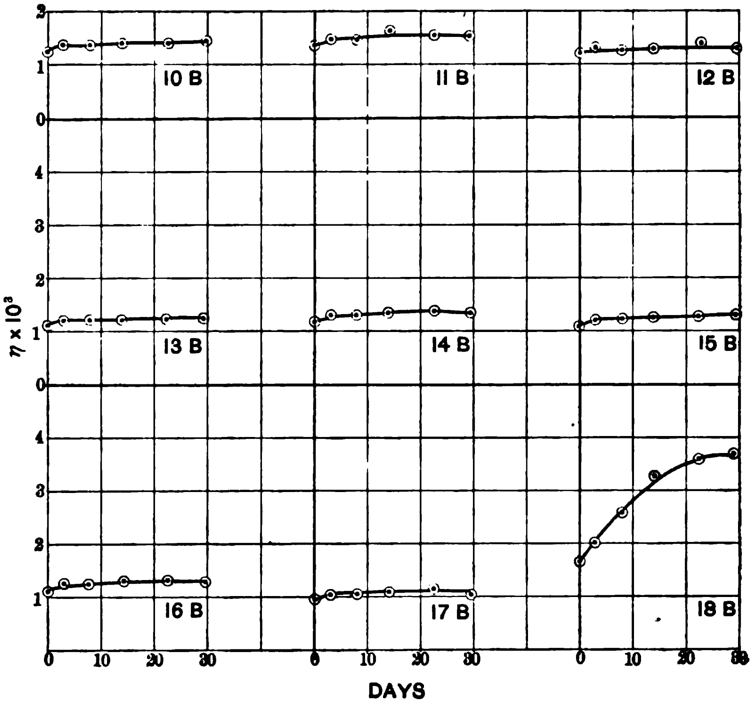

2
1
0
4
3
2
1
0
4
3
2
1
η x 10³
10 B
11 B
12 B
13 B
14 B
15 B
16 B
17 B
18 B
0
10
20
30
DAYS

Fig. 8.

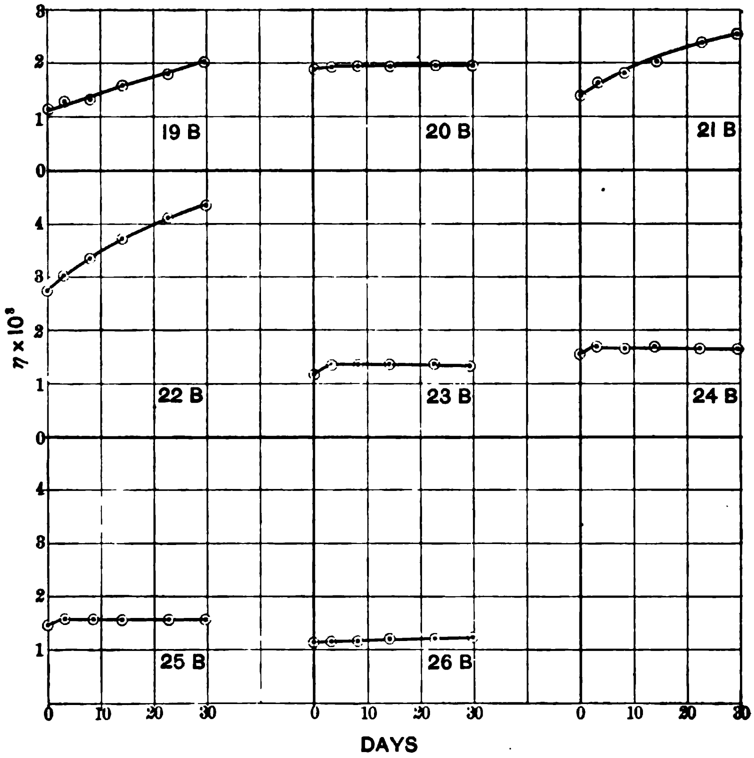

3
2
1
0
4
3
2
1
0
4
3
2
1
η x 10³
19 B
20 B
21 B
22 B
23 B
24 B
25 B
26 B
0
10
20
30
DAYS

Fig. 9.

The temperature of the gas muffle used for annealing was measured by means of a resistance pyrometer using a platinum wire having a resistance of 14.78 ohms at 0° C. and 18.64 ohms at 100° C. The temperature is deduced from the resistance of the pyrometer by means of the following formula.[7]

$$t = 100\cdot\frac{R_t - R_0}{R_1 - R_0} - \delta\left[\left(\frac{t}{100}\right)^2 - \frac{t}{100}\right]$$

For commercial platinum

$$\delta = 1.57 + 15\left(1\ 3383 - \frac{R_1}{R_0}\right)$$

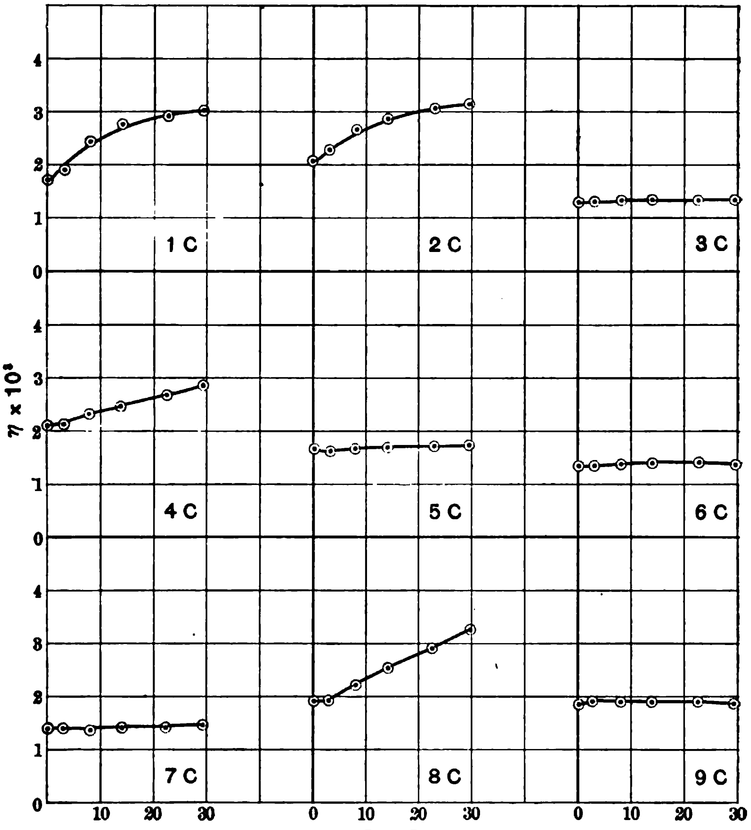


Fig. 10.

where t is the temperature and R_0, R_1 and R_t are the resistances at the temperatures 0°, 100° and $t°$ C respectively. Values were assigned to t, the equation solved for R_t, and the results plotted in a curve showing the relation of t to R_t, from which the tem-

---

[7] "On the Practical Measurement of Temperature." H. B. Collander. *Phil. Trans. Royal Soc.* of London. Vol. 178, p. 161.

perature of the muffle was obtained from the known resistance of the pyrometer.

The relation of the temperature to the time during the first heating and cooling is shown in Fig. 3.

After tying up the specimens in shape for measuring their hysteresis loss, they were placed in a box which had an average temperature of 60° C, with a variation of about 5° C each way, and kept there for a period of 29.5 days; their hysteresis loss being measured from time to time.

Measurement of Hysteresis Loss.—The hysteresis loss was measured in all cases by means of a Ewing hysteresis meter.[8]

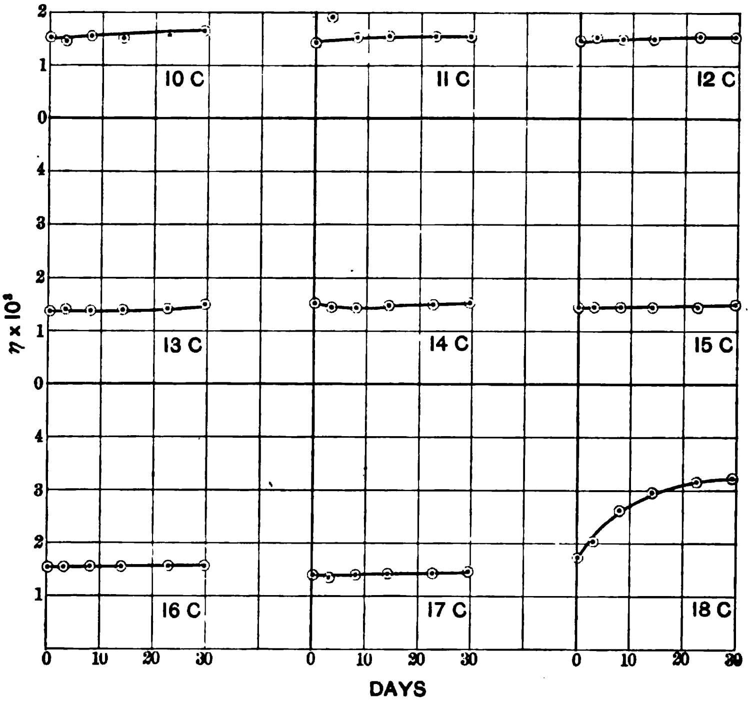


Fig. 11.

This instrument gives comparative values only and therefore requires calibration, for each set of measurements, by the insertion of two standard samples. These samples are sent with the instrument and their hysteresis loss as given is assumed to be correct. Results obtained with this instrument are likely to be in error as much as 3%, consequently two specimens of each sample

---

[8] "A Magnetic Tester for Measuring Hysteresis in Sheet Iron." *Electrical Engineer*, (London). Vol. 29, p. 437.

were taken and the mean value of their hysteresis loss was used in plotting the curves and computing all results.

The hysteresis loss was measured six times during the 29.5 days that the specimens were kept hot. Owing to difficulties due to imperfect heating apparatus and the necessity of allowing the specimens to cool while their hysteresis loss was being measured, the heating was not continuous; but was interrupted for several hours at various times.

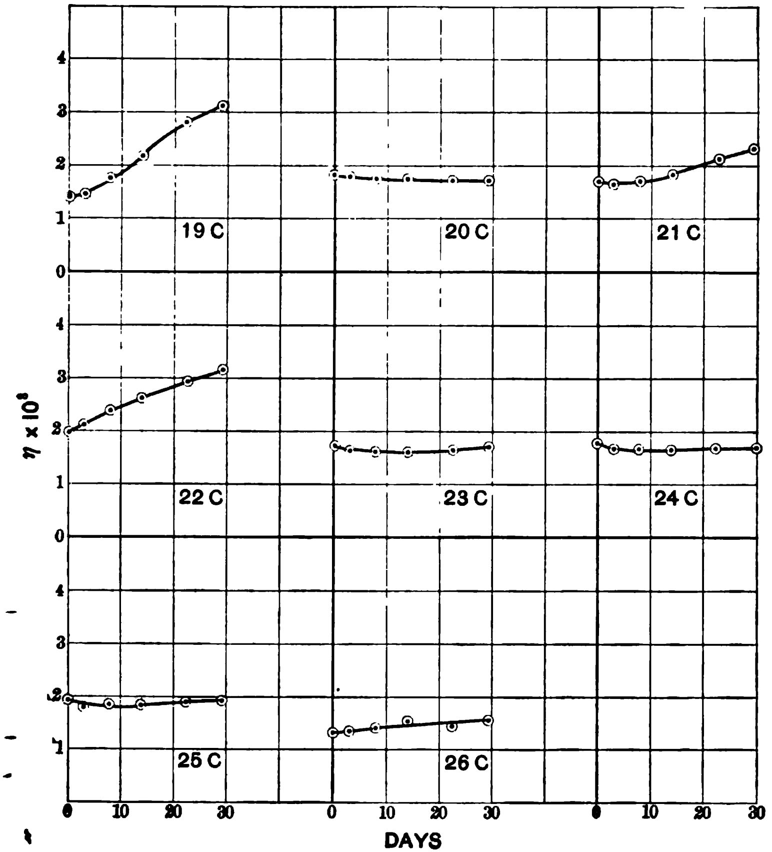


Fig. 12.

A preliminary test of 15 days, which is designated by the letter E, was made on the samples as received. The temperature for this test was 80° C, which was reduced to 60° C for the final test because after correspondence with transformer manufacturers the former temperature was thought to be too much above that normally found in good transformers.

The results of the tests are shown in Table II, and Figs. 4 to 18 inclusive, and are given in terms of Steinmetz's hysteresis constant obtained from the equation $H = \eta B^{1.6}$. H is the hysteresis loss in ergs per cu. cm. per cycle; η the hysteresis constant;

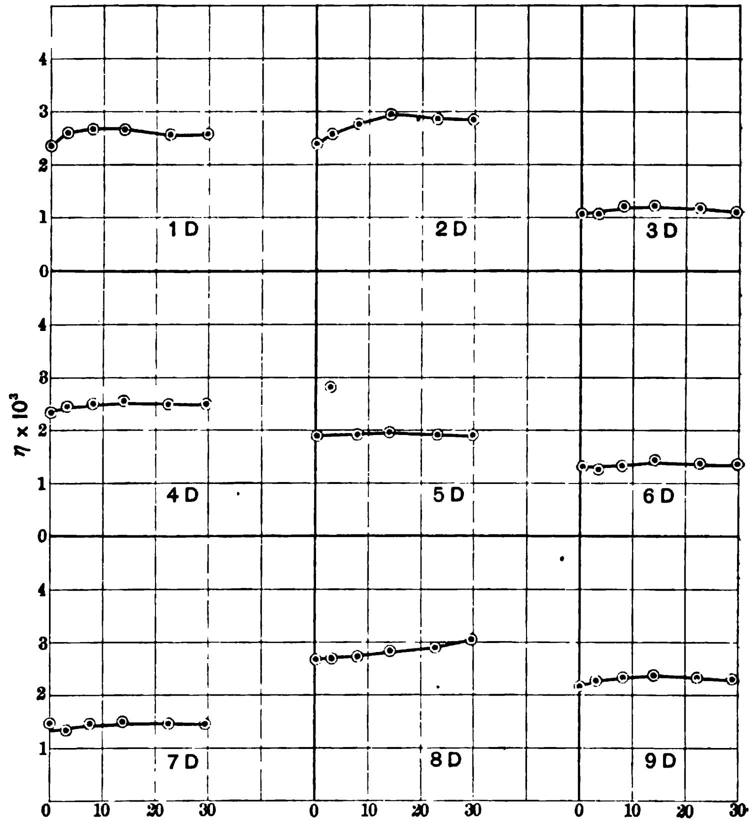


FIG. 13.

and B the magnetic density in gausses. For convenience in writing, the constant is multiplied by 10^3 in the results.

Chemical Composition.—The samples were analyzed to find the amount of silicon, phosphorous, manganese, sulphur and combined carbon which they contained. Table IV shows the results of this analysis.

TABLE III.

Initial Hysteresis Constant × 10^3.

Heat Treatment.

No.	A.	B.	C.	D.	E.
1	3.05	2.60	1.70	2.35	1.72
2	3.03	2.35	2.10	2.40	3.24
3	.96	1.00	1.32	1.05	.90
4	2.55	2.45	2.15	2.40	3.24
5	1.58	1.45	1.68	1.92	1.87
6	.98	.93	1.30	1.25	.98
7	1.22	1.08	1.38	1.40	1.21
8	2.45	1.60	1.90	2.68	4.39
9	1.30	1.70	1.90	2.20	2.01
10	1.40	1.35	1.57	1.75	1.43
11	1.22	1.40	1.46	1.40	1.43
12	1.34	1.30	1.45	1.50	1.31
13	1.18	1.25	1.40	1.35	1.35
14	1.40	1.25	1.45	1.50	1.33
15	1.18	1.15	1.45	1.50	1.16
16	1.30	1.20	1.50	1.50	1.47
17	1.02	1.00	1.40	1.43	1.14
18	1.65	1.62	1.75	1.85	2.33
19	1.35	1.20	1.40	1.55	1.53
20	1.62	1.92	1.80	3.08	3.26
21	1.70	1.40	1.65	1.75	1.95
22	2.75	2.70	2.00	2.40	3.53
23	1.38	1.35	1.65	1.30	
24	1.60	1.65	1.68	1.30	
25	1.54	1.52	1.85	1.95	
26	1.30	1.15	1.45	1.35	

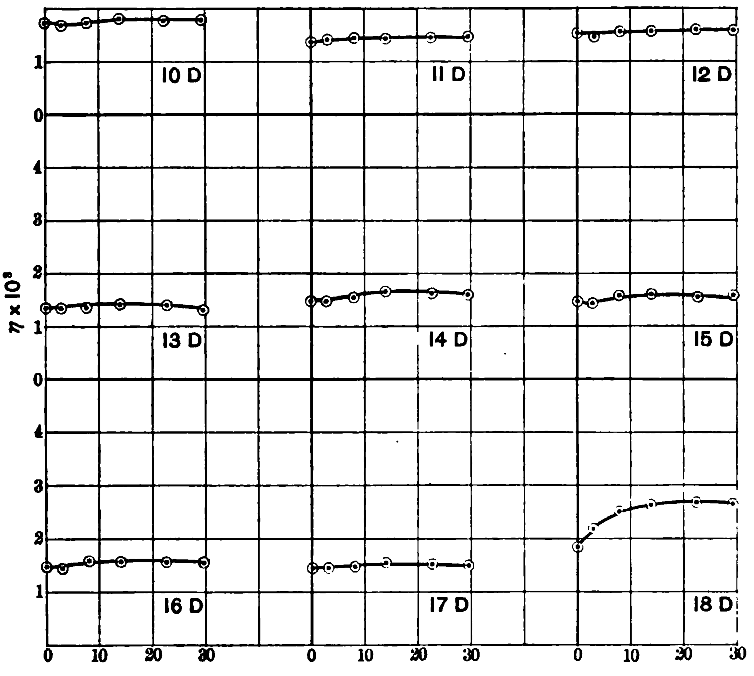


Fig. 14.

TABLE III.
FINAL HYSTERESIS CONSTANT × 10^3.
HEAT TREATMENT.

No.	A.	B.	C.	D.	E.
1	4.15	4.12	3.05	2.57	3.52
2	4.21	3.94	3.18	2.84	4.12
3	.99	1.09	1.37	1.15	1.02
4	3.54	3.61	2.88	2.51	3.90
5	1.69	1.54	1.74	1.91	1.86
6	1.03	1.10	1.39	1.31	.98
7	1.29	1.21	1.44	1.42	1.28
8	4.50	3.71	3.26	3.08	4.51
9	1.38	1.92	1.89	2.32	1.95
10	3.36	1.48	1.65	1.81	1.59
11	1.26	1.49	1.53	1.44	1.42
12	1.41	1.26	1.54	1.56	1.31
13	1.23	1.26	1.50	1.35	1.25
14	1.40	1.32	1.57	1.60	1.30
15	1.25	1.26	1.51	1.60	1.15
16	1.36	1.31	1.59	1.55	1.56
17	1.22	1.04	1.48	1.50	1.15
18	3.43	3.71	3.25	2.65	3.01
19	1.76	2.09	3.13	2.15	2.74
20	1.49	1.98	1.71	3.22	3.26
21	2.64	2 57	2.31	2.32	2.74
22	4.15	4.35	3.20	2.95	4.39
23	1.43	1.32	1.70	1.86	
24	1.41	1.65	1.70	1.81	
25	1.60	1.61	1.93	2.00	
26	1.44	1.26	1.56	1.38	

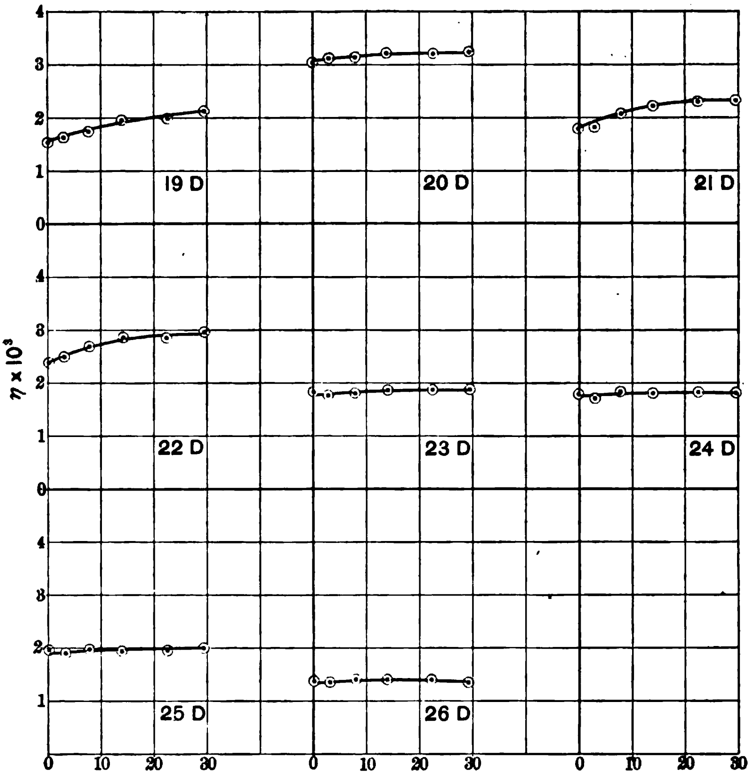


FIG. 15.

TABLE III.

INCREASE IN HYSTERESIS CONSTANT % AFTER 29.5 DAYS AT 60° C.

HEAT TREATMENT.

No.	A.	B.	C.	D.	E.
1	36	58	79	9	105
2	39	68	51	18	27
3	3	9	4	9	13
4	39	47	34	5	13
5	7	6	4	—1	—1
6	5	18	7	5	0
7	3	12	4	1	6
8	84	132	71	15	3
9	6	13	—1	5	—3
10	140	10	5	4	11
11	3	6	5	3	—1
12	5	—3	6	4	0
13	4	1	7	0	—7
14	0	6	8	7	—2
15	6	10	4	7	—1
16	5	9	6	3	6
17	20	4	6	—5	1
18	108	130	86	43	29
19	30	74	123	38	79
20	—8	3	—5	5	0
21	55	83	40	33	40
22	51	61	60	23	24
23	4	—2	3	43	
24	—12	0	1	39	
25	4	6	4	—3	
26	11	10	8	2	

TABLE IV.

IMPURITIES IN IRON SAMPLE %.

No.		Si.	P.	Mn.	S.	C. C.
1	Swede Iron	Trace	.028	Trace	.02	.05
2		.066	.120	.16	.05	.05
3	Open hearth steel	Trace	.027	.30	.05	.06
4		.056	.125	.33	.025	.06
5	Steel	Trace	.105	.44	.02	.06
6		"	.059	.27	.02	.05
7		"	.090	.36	.03	.05
8	Bessemer steel	"	.089	.42	03	.08
9		"	.093	.47	.02	.07
10		.028	.089	.25	.025	.05
11		Trace	.056	.38	.03	.05
12	Steel	.017	.071	.37	.018	.10
13	"	.020	.073	.41	.025	.10
14	"	.020	.076	.29	.030	.10
15	"	.016	.060	.37	.02	.10
16		Trace	.023	.52	.05	.07
17		.006	.075	.43	.03	.07
18	Iron	.048	.210	.10	.02	.06
19	Bessemer Steel	Trace	.102	.39	.06	.05
20	" "	.009	.064	.39	.02	.09
21		Trace	.093	.30	.07	.06
22		.040	.085	.34	.02	.07
23		Trace	.099	.36	.03	.07
24		"	.071	.34	.02	.05
25		"	.074	.27	.02	.09
26		"	.101	.26	.03	.05

Discussion of Results.

In order to make the relation, if one exists, between the hysteresis phenomena and the impurities in the iron clearer, three sets of results were plotted. These show the relation between (1.) the various impurities, taken one at a time, and the initial hysteresis constant; (2.) the various impurities, taken one at a time, and the increase in the hysteresis constant; and (3.) the various impurities taken two at a time and the final hysteresis constant. Samples of these results as plotted are shown in Figs. 19 to 21 inclusive. The relation between the final hysteresis constant and the sum of the impurities was also plotted, Fig. 22.

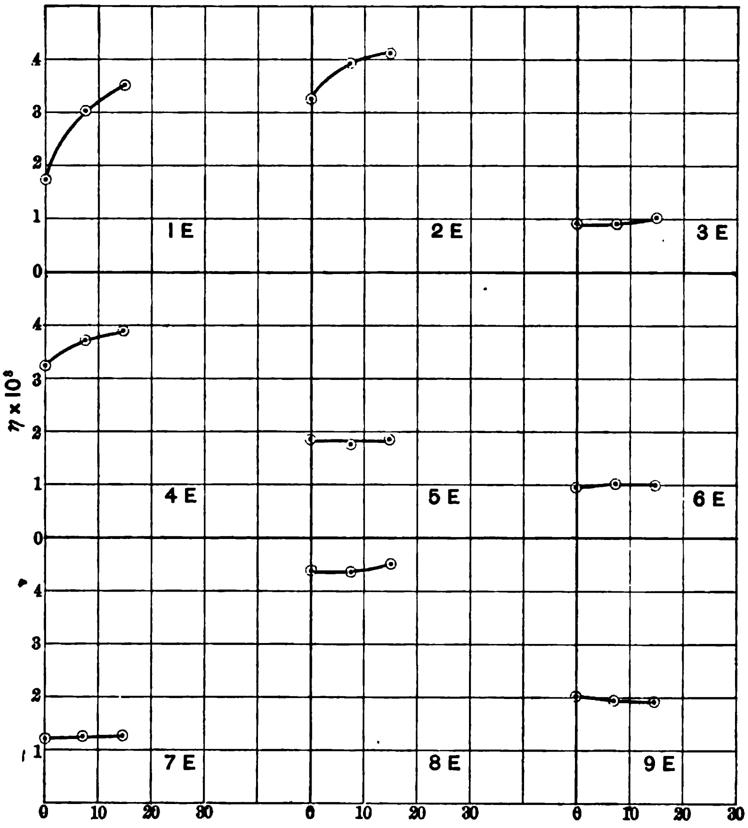


Fig. 16.

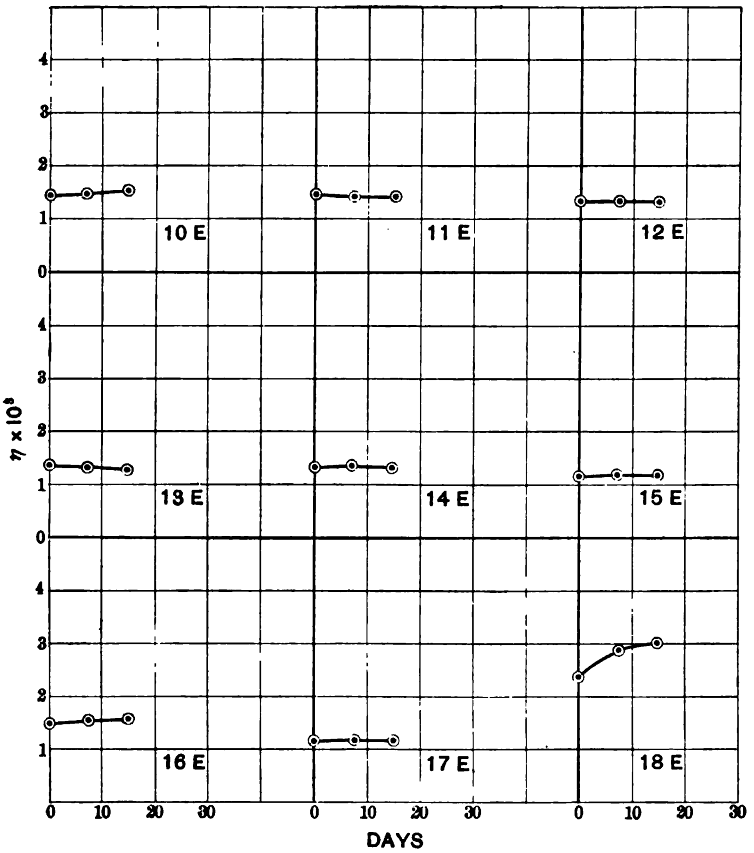

η x 10³
4
3
2
1
0
10 E
11 E
12 E
13 E
14 E
15 E
16 E
17 E
18 E
0
10
20
30
DAYS

Fig. 17.

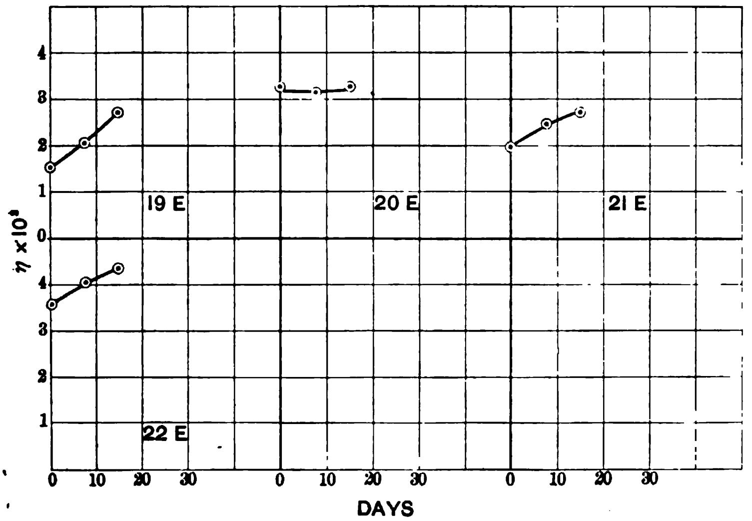

η x 10³
4
3
2
1
0
19 E
20 E
21 E
22 E
0
10
20
30
DAYS

Fig. 18.

From an inspection of these results it is evident that neither a single impurity nor pair of impurities has any preponderating effect on either the absolute value or the increase in value of the hysteresis constant. Specimens No. 7 and No. 8 have practically the same chemical composition but differ widely as to hysteresis constant and aging.

A comparison of the constants after the different heat treatments shows that the structural difference which probably causes the difference in the hysteresis phenomena is not materially affected by annealing or quenching if the temperature is below 850° C. It is noticed that specimens, Nos. 1, 4, 8, 18, 21 and 22 have their final hysteresis constant reduced by quenching from a red heat; but no cause for this is to be found in their chemical composition. Most of the samples show less effect of aging for the specimens which have been quenched from a red heat, which

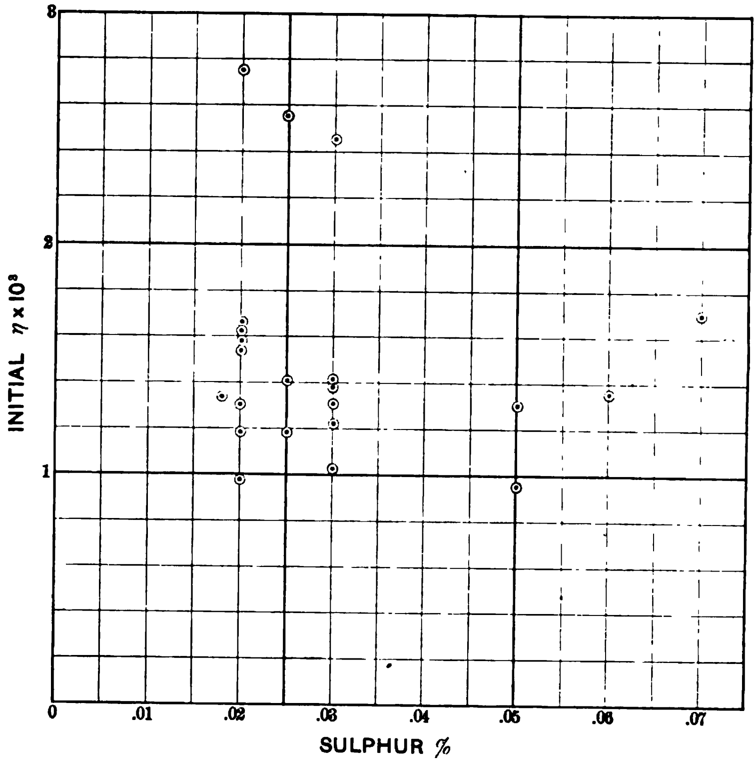


Fig. 19.

is probably due to the iron being in a more rigid state after such treatment and consequently allowing less change to take place at the comparatively low temperature of 60° C.

The best sample tested is No. 3 which is of open hearth steel and is nearly equaled by Nos. 6 and 7 of which the process of working is unknown.

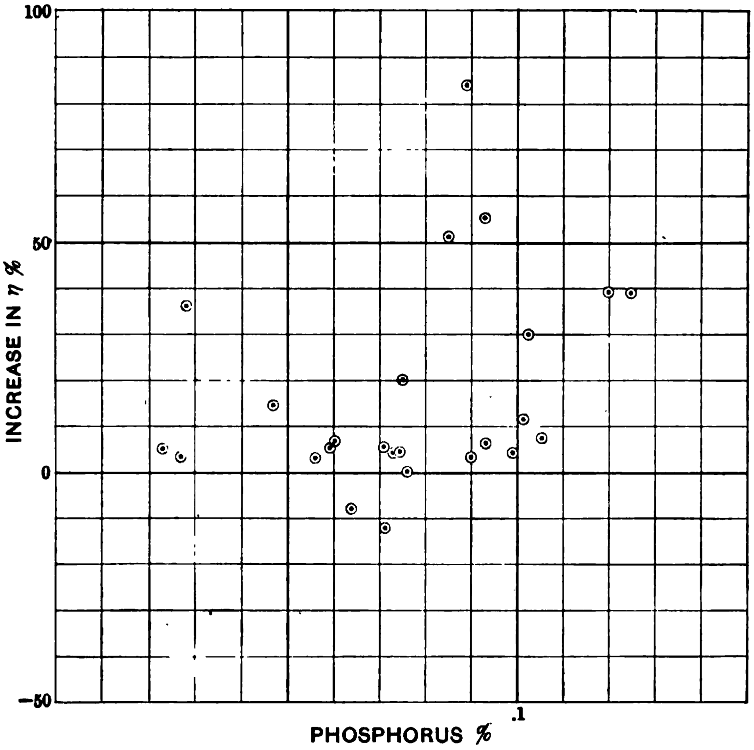


Fig. 20.

By an inspection of the curves showing the relation between the hysteresis constant and time, it is seen that several of the samples show an increase and then a decrease in the hysteresis constant; as is shown more plainly when the iron is kept at a higher temperature.[9]

Conclusion.

The conclusion to be drawn from this research is that the hysteresis constant for iron as pure as the samples tested is not so much dependent upon the chemical composition as upon the physical structure of the material due to the method of working.

---

[9] "Effects of Prolonged Heating on the Magnetic Properties of Iron." S. R. Roget, *Electrician*, (London), Vol. 41, p. 183.

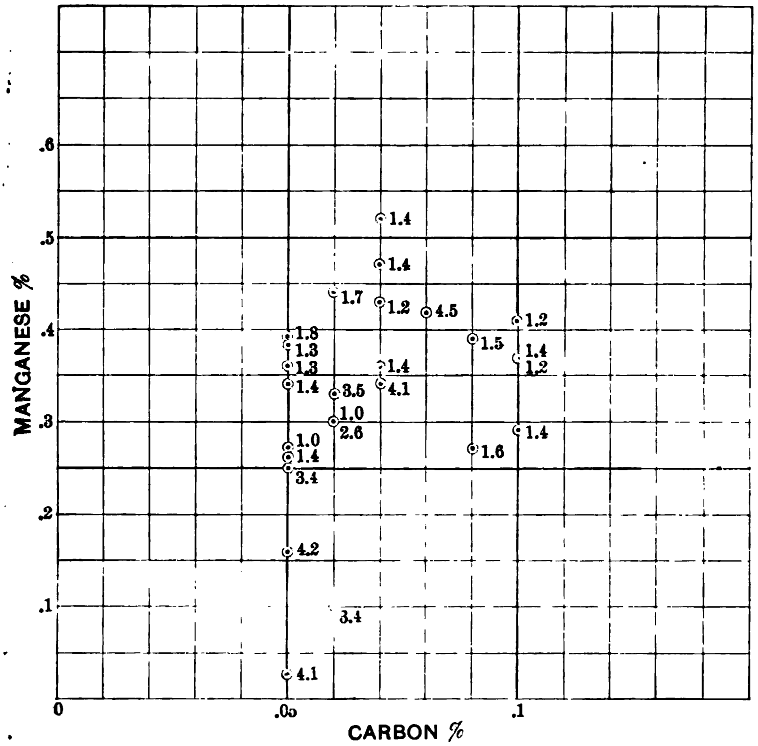


Fig. 21.

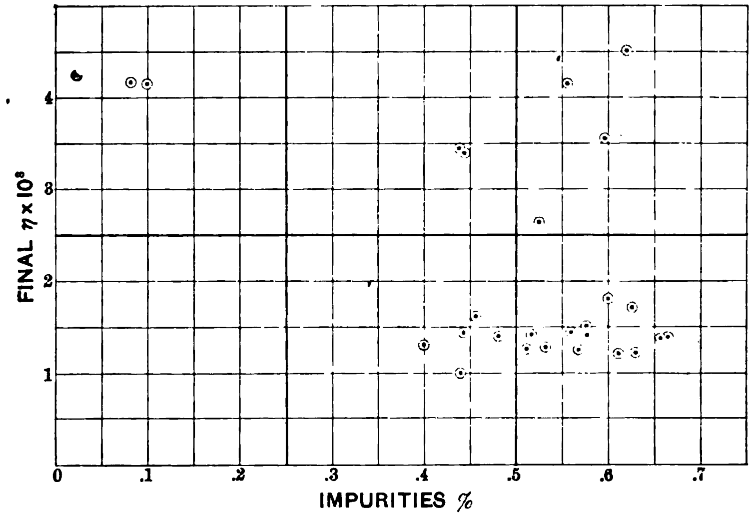


Fig. 22.

The most hopeful direction for future research in this subject seems to be by watching the metal in all stages of its manufacture and studying its microscopic structure.

DISCUSSION.

MR. FORD:—I might say a few words about the origin of these samples. At first I started out to make separate tests of samples cut with their length parallel to the length of the sheet, and samples cut crosswise of the sheet and found that there was some difference in the hysteresis, but owing to the tediousness of making the tests, part of these were thrown out, so that all the samples represented in this paper are samples of different kinds of iron. There may be in some cases iron of two or more thicknesses obtained from one manufacturer. The majority of the specimens were obtained from transformer manufacturers, though some were obtained directly from the iron makers. Some attempt was made to get the method of working the iron, but as you will see from the table this was not entirely successful.

THE CHAIRMAN:—We have listened to a very interesting paper, and discussion is now in order. Before beginning the discussion, however, I would like to ask the author a question for information and explanation. If I understand right, Table III gives the hysteresis constant of iron which has been annealed and then quenched in water. Starting from different temperatures, in the first part of Table III it gives the hysteresis constant after this heat treatment; the second part gives hysteresis constant after additional treatment, and the third part gives increase of hysteresis constant. I do not find, however, the original hysteresis constant before the heat treatment has already been taken.

MR. FORD:—In Table III., column E, you will find the results of a preliminary test made on the samples as received. The only treatment which these samples had received was a slight heating due to the action of the shears in cutting the samples and that due to filing the ends. The samples were placed in a hardened steel clamp and filed to an exact length, which, of course, heated them considerably.

DR. SAMUEL SHELDON:—In Part II. of this paper we have a description of how over a hundred samples of sheet iron or steel have been subjected to various heat treatments, and how the hysteresis losses and the hysteretic constants have been measured for each of these samples after the various treatments. As a result, there has been found either quite a noticeable increase in the value of the hysteretic constant due to the treatment, or very little change at all; in the latter case either a little decrease in the hysteretic constant or a slight increase. The different heat treatments seem to show no like effect on the different samples. It is pertinent to ask what the heat has done to increase the hysteretic constant in those cases where it has noticeably increased it. Transformer sheet irons, like all rolled metals, are allotropic as regards density. In the direction of the length of the sheet there is less density than there is in a direction at right angles to that of rolling. Sheet iron, in order to have a small hysteretic constant, should be least dense in the direction of magnetization and most dense along the magnetic equipotential surfaces. Now in this case, as was mentioned by the author, after the conclusion of the paper, there was no regular rule followed as to the cutting out of the samples from the sheet. The samples, which were cut out to fit, as I understand it, Ewing's hysteresis measurer, are quite a good deal longer than they are wide, being three inches long and about half an inch wide. In those cases where the length of the sample was along the direction of the drawing out of the plates, or in the direction of the least density, heating would cause a rise in the hysteretic constant. This is because a lessening of the density in a direction at right angles to the magnetic flux has the same effect as an increase of density in the direction of the magnetic flux. Compacted bodies which have been passed through rolls, when afterward subjected to heat, increase in size in a direction at right angles to the direction of rolling and the increase is a permanent increase. This was called to my attention first, I think, in connection with some brass binding-posts, whose perfectly fitted screws were heated by a current passing through them. As a result they grew so large in diameter that they would but tightly fit their holes. They were turned down so as to fit loosely and they were again heated. Again they grew large enough to fill the holes. Under the application of heat, they grow and permanently keep a larger diameter. The mere heating of a sample of iron, which has just come from the rolls, would increase the hysteretic constant, if the magnetization were in the direction along which the strip had been pulled out from the rolls; it would increase it permanently. If, however, the magnetization were at right angles to the grain of the metal, the increase of size in the direction of the magnetization, due to heating, would decrease the hysteretic constant, and the accompanying increase of size in the direction which is at right angles with the previous direction and which is in the direction of the thickness of the plate would increase it to about the same extent. Now it seems to me that those samples, which upon test have shown no very marked increase or decrease, were cut out so that afterwards the magnetization was in a direction perpendicular to the grain; whereas those which have shown a marked increase in the hysteretic constant were cut so that the magnetization was in the direction of the grain.

Mr. Ford:—I would say in this connection that about the first fifteen samples, I believe, were those of which I had specimens cut both ways of the sheet, and, as I remember it, those which were tested finally were those in which the magnetization was parallel to the grain of the iron; but in the preliminary test, referred to in column E, no difference in the aging was noticed between those which were cut at right angles to the grain and those which were cut lengthwise of the grain.

A matter of interest in this connection is the effect of intense cold on the hysteresis constant. We usually consider that this is rather stable at or below atmospheric temperature; but such is not the case, as was shown by a simple experiment. Four specimens of sample No. 14 (steel) were taken, and by mixing the sheets of which they were composed their hysteresis constants were made equal.

Specimens cut side by side from the same sheet will have different constants, so that this shuffling was necessary in order to have the four samples the same. These samples having an initial hysteresis constant of .00124, were put in a beaker of liquid air having a temperature of, approximately, — 210° C., and allowed to stay there until thoroughly cool.

They were then taken out and put in the hysteresis tester and the constant determined while they were cold, and found to be .00159. After this they were warmed to the temperature of the room, about 20° C., and the constant found to be .00139, showing a permanent increase in the hysteresis constant of 12% and a temporary increase of 28%.

MR. STEINMETZ:—[The Secretary, in the Chair] This paper is very interesting in what it gives and what it does not give. It does not really give a solution of the problem, namely, why does iron age, and how can aging be avoided, nor does it give the reason why one sample of iron has a high hysteresis loss and the other a low hysteresis loss. It only shows again that the chemical constitution has nothing to do with the hysteresis, but that hysteresis loss depends largely on the physical constitution of the iron, and on the chemical constitution probably only indirectly in so far as the physical constitution depends on the chemical to a certain extent. That is, very pure iron probably is independent of the chemical constitution, but as 1% or 2% of carbon gets in, you will find entirely different values of hysteresis constant because you find entirely different physical constitution. You find this in brittle cast iron for instance. There is one feature which strikes me in all these tables: that is these very low values of the hysteresis constant, some going down below 1. Now these are values very much lower than I have found, and I am very suspicious that the absolute values are not correct. I should rather suspect, and believe we have reason to suspect, from my knowledge of the instrument with which these tests were made that there is a constant error in all the readings, which makes them less than they should be. This does not impair the value of the paper, but merely means that we cannot rely on these measurements. Referring to Table III. the lowest of which I have absolute record is 1.24, and that was a very exceptionable case, and here are quite a number which go far below that. But there is one very interesting feature regarding this aging in the table giving the percentage of aging. That is, we do not find that the different kinds of iron age differently, but we do find that some iron does and other iron does not age, because you see there are hardly any intermediary values. All these values are very low values, all values of a few per cent., and a few per cent. we can hardly count upon as proving anything, because you must expect in different conditions on different days iron will vary a few per cent. or its physical structure change slightly. If you exclude small changes in the hysteresis values, changes of 5 or 6 per cent., we find that here about three-quarters probably of the samples of iron do not change noticeably, while the rest change by very large values. But that means that really there are two kinds of iron: that kind of iron that changes, ages considerably, and that kind of iron which does not change. These tables are very interesting, although for a different reason: namely, here samples of the same iron have been exposed to different treatment. First, hysteresis loss has been taken as they were received, then after annealing at 800° C., then after annealing and quenching at 200°, 400° and 800°. Now you compare the different values A, B, C, D, and E and you will find one interesting feature, that in most cases a minimum value of hysteresis constant occurs at B or C. Take for instance the first part of Table III., the first line, No. 1, the minimum is at C, you see, in No. 2 the minimum is again at C, No. 3 is an abnormally low value and does not agree with that. In No. 4 you find the minimum, at C. In No. 5 you find the minimum at B. That points to one feature, that there is a certain temperature of quenching at which the hysteresis constant reaches the minimum and that this temperature is as a rule between 200° and 400° C. That accords fairly with my experience that a certain temperature gives the minimum value of hysteresis loss, and if you go beyond that temperature you get higher values, and if you go below that temperature you get lower values again of hysteresis constant. The temperature in most of these tables here seems to have been 200° to 400° C. That is all that I can say about it. Perhaps I might suggest an explanation of this aging: that each sample of iron has a certain value of hysteresis constant at one temperature, a different value at another temperature. The hysteresis constant is a function of the temperature, and the physical constitution of the iron also a function of the temperature, and by maintaining the iron at this temperature for an infinitely long time it reaches this permanent value. Now by exposing the iron to a different temperature, either higher or lower, or by mechanically treating it, or in any way changing the physical constitution so that it does not correspond to what it would assume at a temperature of 60° C., then when we maintain it at 60° C. it gradually will change the physical constitution, the limiting value corresponding to the stable state of 60° C., and we will therefore probably find this aging which may, as some of these tests show, be negative. That is, the hysteresis constant may decrease, although as a rule it increases. It increases because the iron has been brought to this temperature from a higher temperature from annealing, and we know that as a rule the hysteresis constant as a function of the temperature decreases with increasing temperature of the iron. Raising the iron first to high temperature and producing the physical constitution corresponding to the high temperature, and then maintaining it at low temperature it will gradually increase in hysteresis loss until it assumes a value corresponding to this lower temperature. I do not know whether this explanation is correct, but some features seem to point to that. This gradual increase of hysteresis, for instance, with some kinds of iron and almost constancy in other kinds of iron: that is, increase, not uniform, but increase first fast and then slower and slower, seeming to tend to a constant value.

MR. I. A. TAYLOR:—I was interested in one point Mr. Steinmetz made, that some irons have an increase in their hysteresis loss and others do not. Several of the manufacturing companies have from time to time made claims that they supplied non-aging iron, but in trying to get stringent guarantees about a year ago, it was found that the best that could be done was to obtain a loss of less than about 10% aging per year for two years, which would seem as though, from a commercial standpoint at least, the non-aging variety is still rather difficult to obtain. However, as compared with some of the iron tested by Mr. Ford, 10% per year might be termed extremely non-aging.

It seems as though the more important result of aging has been overlooked—that while the increased all-day losses and the cost of supplying the same have received entire attention, they are really of little more than academic interest; but the fact that the temperature elevation increases in direct proportion to any increase in the total transformer loss, and therefore must increase on account of aging, not theoretically, but practically sufficient to make it impossible for a transformer to carry its rated load after it has been used a few years, is a much more important item.

It is only on this account that it is absolutely necessary commercially to keep the proportion of the iron loss to the total loss down to about 50% or thereabouts. If the iron loss could be raised without fear of dangerous increase due to aging, and the copper loss correspondingly lowered, the better non-inductive regulation would make it possible to use incandescent lamps of at least 15% better economy than are at present possible on alternating current lines. Certainly if transformers can be obtained which will not age practically, it will be a great advance in the interest of the alternating-current central station.

THE CHAIRMAN:—If there are no further remarks Mr. Ford will have an opportunity to close the discussion.

Mr. Ford:—In regard to what has been said about the hysteresis meter, I quite agree with Mr. Steinmetz in doubting the absolute value of these readings. Any one who has worked with a hysteresis meter knows that it is a very convenient apparatus to get comparative results with, but when it comes to absolute values it is quite difficult to calibrate. The samples which came with this hysteresis meter were from Prof. Ewing's laboratory and accompanied by a certificate signed by him, so that they are presumably correct. I might also state that the tests referred to under E in Table III. were obtained with another hysteresis meter. The ultimate calibration and comparison of these meters went back, however, to a certain pair of samples, but they were compared with other samples which were sent with another hysteresis meter, and the two sets of samples agreed quite closely.

The Chairman:—Before relinquishing the Chair, I wish to say that we have the privilege this evening of having with us one of our members from a very distant point, Mr. Peirce, of Johannesburg, where he is the leading electrical engineer of the Consolidated Gold Fields of South Africa, a part of the world that is now of unusual interest to all of us. Mr. Peirce found it necessary in October last to detach himself from the interests at Johannesburg and he is now in this country engaged in finding a solution to some very interesting electrical problems connected with the mines. Perhaps this evening some of the gentlemen present may be able to assist him in regard to any inquiries he may make.

Mr. A. W. K. Peirce:—Mr. Chairman and Gentlemen, I don't know that anything that I can say would be of particular interest. Perhaps, though, you might like to hear what has been done in electrical work in that country which Mr. Pope has referred to so feelingly. I have been out there about four years. At that time they were just beginning really to wake up to the possibilities of electrical power transmissions and other applications. Previous to that date their work had largely been lighting, and the only plants installed were small plants of all kinds, sizes and description and usually rather poor. I know I saw some machines there that carried me back to the very early days as I remember them. They consisted of a field frame and a pair of bearings and the armature, all supported on a timber bed-plate. The only connection between the bearings and the frame was a wooden bed-plate, and there were other freaks of that description. As I say, they have just begun to awake to the possibilities of electric power transmission, and now they use electric power quite extensively. There is one large company there that established a plant for the purpose of supplying power generally along the line. In the first place let me say that the central mining region there, the Witte Water Rand, occupies a stretch of country about 25 miles long and a few thousand feet wide, a long strip of country, and at one end are some coal mines which produce a fair quality of bituminous coal, which makes it, of course, very convenient, and a project was started for establishing a power plant at one of these coal mines, using the waste coal as it came out and distributing the power at high tension along the reef, and that was done. They have a plant of about 2500 K. W. installed capacity and stepping up to 10,000 volts, transmitting over a pole line about 25 miles long. All along the reef, branch lines are taken off at intervals wherever required, and then stepping down to suitable voltage they use it for other purposes, usually for motors. The suburban district of Johannesburg is lighted largely from this plant. The local plant was of insufficient size and they could not raise money to buy any more. This plant is operating well, although they had a great deal of trouble with their insulators from the severe lightning storms that take place during the summer months in that country which proved a little too much for them. I may say that they were not high-tension insulators, such as are used in this country, but simply a large edition of the ordinary porcelain pole-line insulator, and with those they had a great deal of trouble and with some very curious results. They would apparently explode at times and fragments of an insulator would be found up to 40 and 60 feet away from the poles. They are iron poles, and a little moisture had probably crept through a crack in the porcelain and the explosion was due to steam generated. Wooden poles cannot be used on account of the ants. They have a life of only about two years; so iron poles are used altogether, and on this particular transmission, which is the one where high-tension transmission is used, they are up to date. They also use iron arms and with iron pins in the insulators, so that the insulation of the line depends entirely upon the porcelain of the insulator. This line is spiral throughout its whole length, but at the same time it interferes with the telephone system. They have quite an installation of motors at various points, one of 250 H. P. The others are all smaller, and, as I say, they light the town of Johannesburg. The maximum load on that, up to the time I left, was about 1800 K. W. during lighting hours of the evening, and the day load about 1000 to 1200, depending somewhat upon the weather. The only other plant, other than that used for individual mines, is a transmission plant belonging to the Consolidated Gold Fields, they owning a group of mines in the Central Rand covering a stretch of territory of about five miles along that reef. In the center of this territory they established an electric plant for the purpose of supplying power to the various companies in that district which they control. The 10,000-volt plant is—I don't know that I mentioned it—long-distance transmission with 3-phase; this plant also is a 3-phase plant of about 1500-K. W. installed capacity, generating direct at 3300 and transmitting over this five miles of ground. This current is used largely for pumping in the mines, and the high-tension current is carried directly down the shaft in some cases 1500 feet. That is the greatest depth at which we have any pumps installed. They use 3-wire rubber insulated and lead-covered and iron-armored cables, and they have given excellent results. The high-tension current is carried underground and transformed there, and low-tension induction motors are run from the transformer. They have been very unfortunate with one of their mines there in having a great deal of water to contend with, far more than was anticipated, but the electric pumping system has demonstrated its flexibility, as they were able to take care of the unexpectedly large increase in the amount of water necessary to handle with much more ease and less expense than has been the case with other systems of pumping; so much so that they have decided to go in entirely for electric pumping in the newer mines that they are laying out. The favorite pumping installations along the Rand consist of 3-throw pumps usually geared to suitable motors. There are several direct-current installations, but they are not so satisfactory as the induction motor, on account of the dampness, but principally on account of the lack of intelligent operators. Being underground, in a dirty, wet place, they do not get very much supervision, and the men who attend them are not of a grade of intelligence to exercise proper care and judgment in looking after them. On account of the great amount of lampblack always in the air from the kerosene lamps used for light for the mining operations, there is an excellent chance of breakdown of insulation, which very frequently has taken place. With the direct-current machines, also with several installations of induction motors, where they have attempted to use a comparatively high-tension current, such as one installation there which ran at 936 volts or something like that. All of the other mines have only small plants, usually, as I said before, for lighting or for small local transmission, although there are several plants now on order or under way for larger uses. But the principal problem which will arise in connection with the South African mines is that of deep level, on a large scale, probably larger than has been attempted anywhere in this country. The conditions are that the reef carrying the gold dips into the earth at an angle of approximately 35 degrees, and it has proved its permanence so far, both in size and value, to an extent which has warranted them in laying out properties which will demand vertical shafts to intersect this reef at a depth of 7 to 10,000 feet, probably 8000 feet would be the limit within the next six or seven years. Now the problem of hoisting from depths of that kind with a single hoist at the surface becomes very severe on account of the weight of the rope. The rope must be made so strong, in order to support its own weight, that you soon reach a limit that with the amount of power required and the weight of rope and the size of apparatus becomes prohibitive. Therefore the problem of winding in stages presents itself. That is, it would be necessary to install a hoist at the surface which would haul from a depth of, say, 3000 feet; at that 3000 feet install another hoist which would haul from 6000 to 3000 feet, and at the 6000, if necessary, install another hoist to hoist from seven, eight or 9000 feet, as the case may be, up to the 6000, and the hoist must be capable of handling a large amount of ore and at a high hoisting speed, that is to say, six tons and over in each skip, with a hoisting speed of 3000 feet a minute. That is the usual specification. And, as I say, it must be capable of being operated at a depth of 3000 feet. That introduces problems, I think, which other mining industries have not had to face as yet, but it is a very real problem there. Now there are three possible hoisting methods: Steam, which is at once out of the question—well, at any rate, it is inadvisable to take steam down 3000 feet into the ground—then there is compressed air and electricity. One of the latter two will do the work eventually. If it can be demonstrated that apparatus can be built for doing it successfully, electricity has so many other advantages that there is no question as to which will be the power adopted. But that is a country which is about six months away from the manufacturers. That is, it takes a month for an order to go from there to the manufacturers and then three or four months to ship the stuff out. Therefore it is impossible to try experiments there. There is altogether too much at stake. Of course every responsible manufacturer guarantees his output and will make good any defects, but if in the meantime the making good of the defects hangs up a mine which is counted on to make a profit of $150,000 a month or something like that for a period of six months, the repairs on $10,000 worth of apparatus are not of great importance. Therefore, as I say, there can be no experimenting done there, and this is the problem which we have to face, and of course I hope that the developments will be such that electricity will be the motive power adopted. I might say that for this kind of work there would probably be two hoists in each shaft, and there are probably under estimate at present, that is, being laid out on paper, at least twenty shafts ; that means quite a hoisting plant altogether. Of course all those shafts are not controlled by one company, but the Consolidated Gold Fields alone has an extent of ground which will probably require about eight shafts, with two hoists of a capacity to do the work that I have mentioned. It is with the hope that I may be able to see in operation in this country something that will approach that kind of work and something that will show that the problem is quite capable of being absolutely met, not partially, that I have come to the United States to see what is being done, and if there is any one here who can give me any information on that subject I should be very glad indeed to receive it.

As regards the general features of power plants there, I may say that this large central station, the 10,000-volt plant that I spoke of, uses the waste coal from one of the mines. It was not exactly waste. The dust is sifted out, but they use the fine coal and it is fed into the furnaces by a kind of mechanical stoker arrangement, which is not exactly a stoker, as it fans the coal in. There is a revolving fan, like a paddle-wheel, under which the coal is dropped, about a teacupful at a time, and it sprays it into the furnaces, so that really there is only a very thin fire, and the grate bars consist of perforated iron plates, about eighth-inch holes or something like that, and this coal is spread in on top of it and cleaned by hand. All of the other plants, the general power plants, aside from electric plants, use hand firing, usually a very poor quality. The coal supply is ample but the quality is rather poor. The ordinary coal gives an evaporation of about six pounds of water per pound of coal with water-tube boilers and under good conditions as to draft and so on. The water-tube boilers are used almost exclusively, except in some of the older plants, which have been equipped for a number of years, where Lancashire boilers are used. As to the engines, I think there are no two alike so far as makers are concerned; some are low, some high, some vertical and some horizontal, Corliss and slide-valve and piston-valve and all the different kinds, I think, are represented there. Compressed air is very largely used, of course, for the rock drills, and I should say that about as much power is used for driving air compressors as anything else, that is, steam power. There is only one instance where an air compressor is driven by an electric motor, and that is the 250-horse power motor I mentioned in connection with the high-tension plant. I think there is a representative of every voltage known to history, from 45 to 200 for lighting circuits, advancing by about from 3 to 5-volt steps. I know of one mine alone that had for lighting circuits one 45-volt circuit, one 60-volt circuit, one 75-volt circuit, one 100-volt circuit, one 120-volt circuit—that was a good commercial machine—and one 200-volt circuit. That was in use on one mine alone. Every time they changed engineers they would change the plant a little. Those were small machines, about 10 K. W. The new engineer would make an addition to the plant and it would have to be something different from what had been there before. That same mine to-day, however, is running from a central station and has transformer step-down stations and always runs with alternating current, and all the old plants have been torn out.

I don't know that there is anything else that I could say particularly in regard to electrical matters, and in my short stay in this country I think I have pretty well exhausted myself on political matters. That seems to be a very general subject here, but if there is any information that I can give about any conditions there, aside from political conditions, I shall be very glad to do so.

THE CHAIRMAN [Mr. Steinmetz]:—I am sure we are all very much obliged to Mr. Peirce for his very interesting account of the electrical conditions in South Africa and the development of electrical industry in that far-away but highly interesting region. I would like to ask him one matter which I did not quite understand:—what was the capacity that these deep-level hoists required?

MR. PEIRCE:—They have to hoist about six tons of ore in each skip at the rate of 2500 to 3000 feet a minute, a maximum of about 3000 feet a minute. It makes something like 800 to 1000 horse-power per hoist and the hoists have got to go down a hole in the ground 5 ft 6 in. x 6 ft.

THE CHAIRMAN:—There is one point that might be of some interest to our members and that is whether Mr. Peirce can inform us what type of machinery is mostly used there. Where do the South African people mostly go to buy machinery? Do they get it from Continental Europe, England or America? In other words, in what proportion about are the different manufacturing countries represented in supplying the South African market?

MR. PEIRCE:—I do not think that there is a manufacturer of electrical machines that has not a machine on the Rand to represent it; but the majority of the machines there, so far as capacity goes, come from either the United States or Germany or Switzerland. Most of the older direct-current apparatus is of English make, but the later plants are almost entirely either American or Continental, that is, German and Swiss. I should say that in actual kilowatt capacity, Siemens and Halske have the greatest capacity of machines represented there. That is, the German firm of Siemens and Halske. But that is partly accounted for by the fact that they undertook to equip this 10,000-volt transmission plant that I spoke of, and of course that is entirely their machinery, both in the station and for the consumers.

THE SECRETARY:—I would like to ask Mr. Peirce about the drifts that follow the reef between the shafts, to what extent they are worked. Of course when they get down to the reef they can work out laterally and follow the reef along. How far do they follow it? The reef runs at an angle and they run down from the surface to intersect it; then, when they strike that reef do they follow it?

MR. PEIRCE:— Then they turn off and sink a shaft of about the same size right down the reef and mine off from this shaft to one side or another. The convenient-sized mining property is about 4000 feet long by 3000 deep; that is, 4000 feet parallel to the reef and about 3000 feet in the direction of the dip, and there will probably be two shafts sunk on that property so as to divide it up approximately equal, sunk near the point where they will strike it soonest, that is, where the reef is at the least depth, and they follow down the incline of those shafts and mine off to each side until they have taken out the entire gold contents of that piece of ground.

THE SECRETARY:—Then do these claims really intersect?

MR. PEIRCE:—No. The mining laws are different from the United States mining laws. According to United States laws a man pegging out a claim on a reef can follow that reef wherever it goes; but according to Transvaal laws he can only mine vertically below the surface that he pegs out. He has a vertical section right down through as deep as he wants to go of a size equal to the surface that he pegs out; so that the people who first started in to mine there, where they started to mine on an outcrop, they thought from experience in other countries that probably the gold would only last to a limited depth and they pegged out a certain amount of ground. When they got down into the reef and found it still holding out to the same value and same width, a few of them had courage enough to believe that it kept on in this same way and they pegged out the ground beyond the original limit, but they did not have quite courage enough, and they only pegged out another thousand feet or so, and when they sunk some vertical shafts and found it kept right on the same value and the same width, generally speaking, subject to local variations, they pegged out still further and further south; that is the direction of the dip of the earth, south—until now the ground is all taken up for a distance, I suppose, of four miles south of the outcrop, and the mines are divided into regions depending upon the depth of the vertical shaft. The outcrops, of course, started directly on the surface; the first row of deep levels are 800 to 1000 feet deep. Most of the first row are producing mines now. The second row of deep levels vary from 1800 to 3500 feet in depth; that is, vertical depth before striking the reef, and most of those are in a state of development. The shafts have been sunk to the reef and they have been developed along the reef and they will probably be producing within a year or so. And the third are the reefs where the vertical depth of the shaft would be from 4500 to 6000 feet. They are just starting in to sink the fourth row of deep levels, where they will get the 7000 to 9000 feet shafts. They are all laid out, but no work has been done on them other than on paper, but they will be prosecuted as soon as the times comes.

THE CHAIRMAN:—Can any one of the gentlemen perhaps answer the question asked by Mr. Peirce regarding similar installations and problems solved in the United States? Are there any more questions to be asked? I might remind you that the war in South Africa might stop quickly and then we will not have a chance to have a South African here. They will be so busy that engineers will go from here there and will not come back. If there are no further questions to ask, a motion to adjourn will be in order.

[Adjourned.]

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

—SEVENTEENTH ANNUAL MEETING.—

New York, May 15th, 1900.

The 17th Annual Meeting of the Institute was held this date at 12 West 31st Street, and was called to order by the Secretary at 8 P. M. who announced that in the absence of President Kennelly, and no Vice-President being present, Dr. Sheldon, one of the Managers, would preside.

Dr. Sheldon then took the chair.

The Chairman [Dr. Sheldon]:—The Secretary's announcements are first in order.

The Secretary:—At the meeting of the Executive Committee this afternoon the following associate members were elected:

Archibald, Ernest M.	Electric Laboratory Assistant, McGill University, 103 Park Ave., Montreal, Que.	R. B. Owens. L. A. Herdt. R. W. Pope.
Bowie, Augustus Jesse, Jr.	Draughtsman, Electrical Dept. Union Iron Works, residence, 1913 Clay St., San Franciso, Cal.	J. A. Lighthipe. H. A. Russell. C. W. Waller.
Bryan, Richard R.	Consulting and Contracting Mechanical and Electrical Engineer, 1018 Prudential Building, Atlanta, Ga.	Ralph D. Mershon W. K. Archbold. Thorburn Reid.
Cook, Edward Jerome.	Electrical Engineer, Cleveland Electric Railway Co., 96 Commonwealth Ave., Cleveland, O.	R. N. Baylis. C. J. Field. W. S. Barstow.
Davis, Philip W.	Engineer of New England Office, The Electric Storage Battery Co., Boston, residence, 110 Irving St., Cambridge, Mass.	C. A. Adams, Jr. S. E. Whiting. Gifford LeClear.
De Muralt, Carl L.	Electrical Engineer, 9 Avenue de la Bourdonnais, Paris, France.	C. P. Steinmetz. A. L. Rohrer. E. J. Berg.

Dyer, Shubael Allen	Manager Supply Department Mexican General Electric Co. Box 408, Mexico City, Mexico.	C. F. Beames. P. H. Evans. M. T. Thompson.
Johnson, Chas. E.	Chief Engineer of PowerHouse, Mexico City Tramway, Mexico City, Mexico.	C. F. Beames. Theo. Stebbins. M. T. Thompson.
Lafore, John Armand.	Electrical Engineer, The D'Olier Engineering Co., 125 South 11th St., residence, Overbrook, Philadelphia, Pa.	Minford Levis. Jas. G. Biddle. W. M. Stine.
Murphy, John.	Superintendent. Power Houses. The Ottawa Electric Co., 620 Wellington St., Ottawa, Ont.	A. A. Dion. T. Ahearn. R. B. Owens.
Offutt, Anderson, *B.S.*, *E.E.*,	Assistant Electrician, South Eastern Tariff Ass'n. Care Underwriters Inspection Bureau, New Orleans, La.	A. M. Schoen. E. W. Trafford Jas. A. Wotton..
Robinson, Arthur L.	Electrical Engineer, Southern Railway Co., Box 588 Charlotte, N. C.	A. M. Schoen. E. W. Trafford. Jas. A. Wotton.
Smith, Irving B.	Partner, Chas. Wirt & Co., 1028 Filbert St., Philadephia.	Carl Hering. A. E. Kennelly. Minford Levis.
Thomson, Clarence.	Examiner, The Patent Office, Ottawa, Canada.	A. A. Dion. T. Ahearn. R. B. Owens.
Town, Frederick E.	Superintendent Meter Departments, Potomac Electric Power Co., United States Electric Lighting Co. 706 11th St., Washington, D. C.	C. D. Haskins. C. B. Burleigh. C. C. Haskins.
Trudeau, J. A. G.	329 Kent Street, Ottawa, Canada.	A. A. Dion. T. Ahearn. R. B. Owens.
Viehe, J. S.	Instructor in Electrical Engineering, Lehigh University, residence, 28 Market St., Bethlehem, Pa.	W. S. Franklin. J. H. Klinck. Ralph W. Pope.
Wallau, Herman L.	Electrical Engineer, Brooklyn Heights Railroad Co., residence, 321½ State St., Brooklyn, N. Y.	Sam'l. Sheldon. A. Treadwell, Jr. A. N. Shaw.

Total 18.

The following associate members were transferred to full membership.

Approved by Board of Examiners, January 12th, 1900.

John Denham, Electrician, Cape Government, Cape Town, S. A.

Approved by Board of Examiners, April 18th, 1900.

J. G. White, J. G. White & Co., 29 Broadway, New York City.

Approved by Board of Examiners, April 20th, 1900.

Robert Stuart Stewart, Westinghouse Electric and Mfg. Co., Pittsburg, Penn.

George William Hubley,	Electrical Engineer, Louisville Electric Light Co., Louisville, Ky.
William George Toop Goodman,	Electrical Engineer, Tramway Construction under Public Works Dep't., Sydney, N. S. W.
Eugene Russell Carichoff,	Electrical Engineer, Sprague Electric Co., Bloomfield, N. J.
John Sedgwick Peck,	Electrical Designer, Westinghouse Electric and Mfg. Co., Pittsburg, Penn.

The Chairman:—The appointment of tellers to count the ballots will be next in order. I will appoint Mr. Townsend Wolcott and Capt. Samuel Reber as tellers of election, and they may choose such assistants as they need to help them in counting the ballots. As Proxy Committee I will appoint Mr. William Maver, Jr. and Mr. C. O. Mailloux.

The next business in order is the reading of the reports of the Secretary and of the Treasurer.

The Secretary:—Before the ballots are counted I think it is proper for me to make an announcement as to the course of procedure that has been followed. For the first time since 1893, as you are aware, there has been a certain amount of competition in the campaign, and in carrying on the work of my office I have been guided as far as possible by the Constitution, and previous rulings of the Council. The rulings of the Council in 1893 were, that a member had the privilege of recalling his ballot where it was sent in at any time previous to the election. Another ruling was that where two ballots had been cast by any person, the last ballot cast should be counted and the first ballot thrown aside. It has been usual in all elections to cast aside those ballots which did not bear upon the outside envelope the name of the sender. This of course is necessary, in all events. All ballots turned over to the tellers have been checked off by the membership list, and are correct, barring clerical errors. This will relieve the tellers from the duty of checking off those ballots, if that is entirely satisfactory to the meeting. It should be understood that all apparent irregularities should be settled by the outside envelope, as after the envelope is opened and the ballot taken out there is no way of distinguishing one from another. Therefore if the tellers observe anything that is irregular they will please report it to the Chair.

The Secretary read the following Report of Council for the fiscal year ending April 30th, 1900; together with the Reports of the Secretary and Treasurer; accompanied by a statement from the Cashier of the Mercantile National Bank, stating the balance to the credit of the Institute.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

REPORT OF COUNCIL FOR THE FISCAL YEAR ENDING APRIL 30, 1900.

As required by the Constitution, the Council submits herewith for the information of the membership a report of its work; also the financial standing of the Institute at the close of the fiscal year, April 30, 1900.

Four meetings of Council and six of the Executive Committee, constitutionally representing the Council, have been held during the year.

The completed work of the Committee on Standardization, published in pamphlet form for general circulation, has received extended endorsement, and the number sold indicates that it is being used in practical work. This committee is now co-operating with a committee appointed by the American Society of Mechanical Engineers for bringing about a standardization of capacities, sizes, speeds, etc., between direct connected steam engines and electric generators.

For several years past the Council has reported certain funds as being deposited with different trust companies. During the past year it being evident that such corporations were not in all cases beyond suspicion, it was deemed advisable to withdraw from deposit all surplus funds and invest the entire amount in Government bonds. These 3 per cent. bonds were purchased, $4,000 at 112 and $1,000 at 111¼, commission $2.50. During the year $2,000 had been diverted from the current bank account, in order that it might be placed at interest. This amount constitutes simply a reserve fund, and was established because the bank account was unnecessarily large, and also that the interest might cover the exchange now charged on country checks, which it has done, the accrued interest during a portion of the year amounting to $17.18, while the bank exchange was $6.90.

In accordance with a vote of the Executive Committee May 16, 1899, the Commercial Fund existing was closed, and the cash balance of $289.29 was transferred to the treasurer's general fund. The items formerly appearing in that account are now included in the regular financial report.

By direction of the Executive Committee, the Secretary and Chairman of the Committee on Papers and Meetings compiled and issued to the membership a Handbook, which has proved to be a useful publication, especially for the information of candidates for membership.

As the result of correspondence with the Institution of Electrical Engineers a committee of three was appointed by direction of Council November 22, 1899, to ascertain the probable number of members who would visit Europe this year, and who would probably attend a joint meeting of the two societies should it be arranged for. Favorable replies being received from seventy members, Mr. T. C. Martin, who sailed for London and Paris in March, was authorized to represent the Institute in arranging for a joint meeting at Paris on August 16th.

In order that the files of periodicals might be made more accessible for reference the Council has appropriated five hundred dollars for the erection of two library stacks in the offices of the Institute and the binding of about three hundred volumes.

At the meeting of Council March 28th a committee was appointed to represent the Institute in encouraging the establishment by the Government of a Standardizing Laboratory.

The Board of Examiners has held nine meetings during the year, at which forty-five applications for transfer were considered, twenty-six being recommended for transfer, eleven held over for further information and eight disapproved.

The total membership at the close of last year's report was 1,133, classified as follows:

Honorary Members	2
Members	363
Associate Members	768
Total	1133
Associate Members elected May 1st, 1899, to April 13th, 1900	130
" " " previous year and since qualified	10
Total	1273

Resignations have been received during the year and accepted from the following members who were in good standing:

Members:

PARK BENJAMIN,
ROMAINE CALLENDER,
HAROLD BINNEY,
GEORGES D' INFREVILLE,

Associate Members:

JAMES S. ALDEN,
HENRY W. CARTER,
JULIAN DUBOIS,
FRANCIS M. DYER,
FRANK W. GLADING,
R. N. LARRABEE,
FRED'K. MACKINTOSH,
ERNEST MERRITT,
EVERETT MORSS,
R. H. MACMULLAN,
ALBERT SCHEIBLE,
DANA C. WELLS.

Total Resignations. 16

There have been the following deaths during the year:

Members:

S. DANA GREENE,
JAMES HAMBLET.

Associate Members:

WILLIAM F. KELLY,
CHAS. T. RITTENHOUSE,
ALEXANDER STRATTON.

Total deaths	5
Dropped as delinquent	50
Elected but not yet qualified	19
	90

Leaving a total membership of 1183 on April 30th (a net gain of 45), classified as follows:

Honorary Members	2
Members	374
Associate Members	807
	1183

A list of associate members elected during the year accompanies this report, and will also appear in the Transactions.

The reports of the Secretary and of the Treasurer show in detail the financial standing of the Institute at the close of the fiscal year, together with an itemized statement of receipts and disbursements during the entire year:

SECRETARY'S BALANCE SHEET

FOR THE FISCAL YEAR ENDING APRIL 30, 1900.

Dr.		*Cr.*	
Balance from previous year	$ 634 36	By cash to Treasurer	$13,089 53
Receipts for the year	12,711 65	Balance to next year	256 48
	$13,346 01		$13,346 01

ITEMIZED STATEMENT OF RECEIPTS AND DISBURSEMENTS OF THE INSTITUTE

FOR FISCAL YEAR ENDING APRIL 30, 1900.

GENERAL ACCOUNT.

Receipts.		*Disbursements.*	
Treasurer's balance from previous year	$2,664 46	Revenue Tax	$12 79
Secretary's " " " "	634 36	Bank Exchange	6 90
Entrance Fees	650 00	Chicago Meetings	53 00
Life Membership Fees (G. H. Stockbridge, James Mitchell, C. O. Mailloux, F. W. Hadley)	400 00	Library	8 09
Past Dues	979 75	Ice	24 35
Current Dues	9,031 57	Laundry	7 50
Advance Dues	93 50	Office Expenses	34 15
Standardizing Reports	35 80	" Fixtures	40 21
Electrotypes	39 14	Duties	60
Transactions Sold	508 66	Express	181 58
" Subscriptions	284 59	Telegrams	22 95
Advertising	60 00	Stenography and Typewriting	830 70
Received for Binding	52 25	Stationery and Miscellaneous Printing	699 75
" " Congress Book	4 20	Postage	460 19
" " Reprint Vol. IV	2 00	Messenger Service	9 45
Badges	250 90	Salary Account	2,500 00
Certificates	30 00	Meeting Expenses	261 60
Cash Balance from Commercial Fund	289 29	Rent Offices and Hall	1,100 00
		Engraving	428 14
		Binding	551 68
		Publishing Transactions	2,434 27
		Badges	236 84
		Certificates	12 00
		Reserve Fund	2,000 00
		Compounded Membership Fund	1,132 17
		Appropriation for Secretary, London and Paris	500 00
		Secretary's Balance to next year	256 48
		Treasurer's Balance to next year	2,205 08
	$16,010 47		$16,010 47

All outstanding bills against the INSTITUTE were paid in full April 25th.

There is due the INSTITUTE and probably collectible, $1422.41

The amount reported last year as probably collectible was $805. The amount actually collected was $979.75.

The total receipts for the past year exceeded the previous year by $1,223.69, while the expenses were $1,353.11, showing an excess in growth of expenses over the gain in receipts of $129.42. The net financial gain during the year was $2,005.62.

Property on hand according to inventory, May 1st, 1900.

Office Furniture and Fittings	$ 276.65
Badges	127.00
Catalogue Type and Cases	203.37
Library	300.00
Transactions on Hand	3,293.50
Congress Books	537.00
	$4,737.52

TOTAL NET ASSETS.

Treasurer's Cash Balance	$2,205.08
U. S. Government Bonds	5,000.00
Secretary's Cash Balance	256.48
Property as per Inventory	4,737.52
	$12,199.08
Total assets last year	10,770.49
Increase	$1,428.59

Respectfully submitted for the Council,

RALPH W. POPE,
Secretary.

TREASURER'S REPORT.

FROM APRIL 30, 1899, TO MAY 1, 1900.

GEORGE A. HAMILTON, TREASURER, in account with
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Dr.

Balance from April 30, 1899	$ 2,664 46	
Received from Secretary, April 30, 1899, to May 1, 1900	13,089 53	$15,753 99

Cr.

Disbursements from May 1, 1899, on warrants from Secretary as approved by Council or Executive Committee Nos. 1105 to 1229 inclusive	$13,548 91	
Balance to new account	2,205 08	$15,753 99

The following invested funds appeared in last years report:

Building Fund, Mercantile Trust Co	$ 990 48	
Compounded Membership Fund State Trust Co	1,413 44	$2,403 92
Accrued interest		41 73
To which was added fees of G. H. Stockbridge and James Mitchell		200 00
Reserve Fund created during the year with accrued interest		2,017 18
Balance appropriated from General Fund for Bond purchase.		932 17
		5,595 00

This total of $5,595 has been invested by direction of Council in U. S. three per cent. bonds in the name of the American Institute of Electrical Engineers and deposited in its safe, apportioned as follows:

	FACE VALUE	MARKET VALUE.
Building Fund,	$ 1,000 00	$ 1,090 00
Compounded Membership Fund	2,000 00	2,180 00
Reserve Fund	2,000 00	2,180 00
	5,000 00	5,450 00
Treasurer's balance carried forward to next year	2,205 08	
Total cash and bonds	7,205 08	

Respectfully submitted,

GEO. A. HAMILTON,
Treasurer.

New York, May 15th, 1900.

THE CHAIRMAN:—The Executive Committee of the Council inspected these reports of the Secretary and Treasurer and approved them.

MR. STEINMETZ:—I would like to ask the Secretary how many copies, approximately, of the Standardizing Committee's Report have been sold.

THE SECRETARY:—They are sold at two prices; they retail at ten cents and wholesale at five cents; and the receipts from them are $35.80. So probably there have been, I suppose, between 800 and 1,000 of them sold.

THE CHAIRMAN:—We will now take up the paper of the evening, "Experts and Expert Evidence," by J. E. Hindon Hyde, of the New York Bar.

A paper read at the 17th Annual Meeting of the American Institute of Electrical Engineers New York, May 15th, 1900. Manager Sheldon in the Chair.

EXPERTS AND EXPERT EVIDENCE.

BY J. E. HINDON HYDE.
Of the New York Bar.

The following notes are simply intended to furnish a subject for discussion, for many of the members of the INSTITUTE are much better qualified from experience to speak on the matter than the author, while the others have probably given the subject more thought from personal interest in it than I, as a lawyer only, have bestowed upon it. My duty to my client and the court has been discharged when I have engaged a competent expert to explain the scientific facts and draw therefrom the proper deductions which aid my client's case, and with his expert aid dispel the illusions called up by my adversary, for my adversary's deductions are always illusions.

But it may be useful to explain what I mean by a "competent expert," for it means much more than that he shall have knowledge of the things about which he is to testify.

The subject is of very great importance to us all—to us lawyers, because it is necessary for us to have experts; to the experts, because it is necessary for them to be competent; to us jointly, because we must devise some way to remove the objections which the courts and the public now undoubtedly have to expert evidence.

The newspapers, in connection with a recent famous trial, have shown to us all that the public, as such, derides expert evidence, while in the decisions of the judges we constantly meet with strong criticisms, not only of the mass of irrelevant matter introduced into cases by the united action of lawyers and experts, but even amounting to doubts of the honesty of the experts.

Such expressions as "the usual conflict of expert evidence" and "you can hire an expert to testify to anything," are not uncommon; while in a recent decision Judge McPherson used the following language:

"There is the usual conflict of expert opinion in the testimony, resulting in the usual doubt in the mind of the Court whether such a thing as scientific truth can be said to exist when a question of infringement is being fought out."

Now, while unfortunately there is much truth in these criticisms, there is undoubtedly something to be said on the other side, and at least we can resort to that expedient of a lawyer with a bad case—abusing the adversary—by calling attention to the fact that judges sometimes err, are frequently overruled, and that even the United States Supreme Court has been known to reverse itself.

But the better way is to try to remove the prejudice against the experts. It is not impossible, for I have in mind now a very good expert who died some years ago and whose word carried weight and respect with the judges, because he was known to be honest and straightforward, and his manner was so persuasive and simple that he generally carried conviction to the men to whom he spoke.

Of all the scientific subjectswhich enter into the cases to be determined by the courts, I know of none more important than that of which electricians are making a study. Indeed, I think that I may fairly say that at the present time there is none so important unless it be chemistry, and there is a bond of union between them. And yet I think that the members of the INSTITUTE will agree with me that there is no branch of science less understood in its essential nature and in many of the various possible means of its application to the service of mankind than electricity, not even excepting psychic force, which, for all that we know, may be only a branch of electro-biology. The limits of electro-genesis are not now definable, while the protoplasm itself, and even the atom, must be theoretically considered as both positively and negatively electrified.

But, without passing into this speculative inquiry, it will be sufficient for my purpose to state that in the essentially practical subjects of electro-dynamics and electro-metrics, with their various industrial branches of electro-chemistry, electro-metallurgy, electric lighting, electric traction, electric heating, electrotherapeutics and electrography—all covered by the expression, "the translation of electric energy into heat, light and power," there is a vast field in which electricians themselves still have a great deal to learn, while it is one in which the courts have only their guidance in passing upon very important questions of property rights.

When we reflect that it is almost a century since Oersted's fundamental experiment, laid the foundation for the practical utilization of the electric current for power purposes, it seems strange that we do not know more about electricity than we do, and yet what little has been ascertained is practically a sealed book to most of mankind, including the judges of our courts.

It is not so very long ago that I had to describe to a prominent judge who was hearing an argument in a most important electrical case what a condenser was, and, further, had to explain to him that the current from a battery could be increased by adding another cell. In dictating an opinion on certain patents and mentioning hysteresis, I almost produced hysteria in the stenographer. And I should very much dislike to-day to have to depend upon "judicial notice" being taken of Ohm's law. What does the great body of lawyers know of "harmonics?" What of Foucault currents? What of the relative merits of single and multiphase motors? While few of them remember Lenz's laws of induction longer than from Saturday night to Monday morning.

Neither is it essential, nor even altogether desirable, that lawyers should know all these matters, for if we did we should not have time to learn law.

As late as May 5th, 1898, one of our judges used the following language:

"The mystery and uncertainty which surrounds everything relating to electricity, and the feeling of admiration, almost akin to reverence, for those men who have subdued this unknown and dangerous force and made it do the world's work, make the Court diffident about applying these principles which are axiomatic in the patent law. There is always the apprehension that injustice may be done through failure to comprehend the abstruse and difficult problems presented."

(*Edison Elec. Light Co.* v. *E. G. Bernard Co.*, 88 F. R., 267.)

It must be apparent, therefore, how completely the judges are at the experts' mercy, and how important it is that they should be able to rely upon competent experts. When we remember the enormous number of patents which have been granted for electrical inventions and the vast sums of money that have been spent in litigation, the importance is only emphasized; and when it is recalled that the two most important electrical cases that have been decided by the United States Supreme Court, that relating to the telegraph and that relating to the telephone, were both decided by a divided Court, the difficulties of the judges must be evident. This is also shown in another important case. No one who reads the decision of the Circuit Court in the case of the Edison Electric Light Co. v. Westinghouse, Church, Kerr and Co., involving the patent for the Edison Feeder System, (55 F. R. 290), and compares it with the decision of the same case on Appeal (63 Fed. R., 588), can fail to see how differently different judges regard expert testimony. In the one decision, the expert evidence given by the well-known and even celebrated experts for the complainants is treated as of authoritative weight, while in the other decision it is all brushed aside and the Court decided the case on its own assumption of the facts, owing to the conflict of evidence, and held that Edison had not made an invention.

Once more, the judges' difficulties are illustrated in the recently decided case of *Electric Co.* v. *Scott*, 97 Fed. R. 588, on the Tesla patents, where Judge McPherson's opinion consists almost entirely of quotations from the complainants' brief, which, in turn, are extracts from the experts' evidence.

What qualities, then, make a competent expert, and especially a competent electrical expert?

Perhaps it will not be amiss to point out first some tendencies that are to be avoided.

Bacon, in his "Novum Organum," and Herbert Spencer, in his "Study of Sociology," have indicated many of the biases with which men approach the solution of a question. Some of the special biases of an expert may be enumerated.

1. *The bias of his school.*—The importance of this can hardly be overestimated. It is exemplified in the controversy between the allopathic and homœopathic schools in medicine; that between the advocates of the alternating current and those of the direct current, respectively, for certain electrical purposes; the warfare between the Plutonists and Neptunists, in geology; the dispute as to the first discoverer of induction; the fight over the

limits of deduction and empiricism, the old question as to the nature of sight; the discussion between the followers of Galvani and Volta respectively; the former controversy as to whether oxygen or hydrogen should be used as the standard of atomic weight; the different claimants for the suggestion of the theory of magnetomotive force in a magnetic circuit, with its analogies to Ohm's law and its consequent bearing upon the forms of dynamos, and there are many other cases that will occur to every one.

2. *The bias of race.*—I do not believe that even a scientific man is entirely devoid of this prejudice.

Englishmen know that Scheele discovered oxygen, but they always give the credit to Priestley, while Swedes know that Priestley discovered it, but they give the credit to Scheele. No Frenchman speaks of Adams as the discoverer of the planet Neptune, while Englishmen rarely assign the discovery to Leverrier; and Galle of Berlin is the German discoverer. So, too, the telegraph has been claimed for Steinheil, for Wheatstone, for Davy, for Henry, and for Morse.

3. *The bias of personal dislike.*—This dislike may be either to the client or to the lawyer or to the expert on the opposite side, but it should not be allowed to influence the expert.

4. *The bias of ratio of fees to services*—Of this bias I shall not speak, as we all understand it. The poet Gay has spoken of it in speaking of lawyers. He writes:

> "I know you lawyers can, with ease,
> Twist words and meanings as you please.
> That language by your skill made pliant,
> Will bend, to favor every client;
> That 'tis the fee directs the sense,
> To make out either side's pretense;
> When you peruse the clearest case,
> You see it with a double face;
> For skepticism's your profession;
> You hold there's doubt in all expression.
> Hence is the bar with fees supplied;
> Hence eloquence takes either side."

5. *Then there are also the biases due to the "personal equation."*—There are experts whom I have known who seemed constitutionally unable to answer questions directly and simply. Sometimes the bias takes the form of a seeming choice of unnecessarily involved and stilted language, as if the witness were endeavoring to impress the hearer with a sense of the vast learn-

ing of the expert. Again, it is shown in an apparent unwillingness to admit the truth, and if the admission is finally made, it is prefaced by really unnecessary explanations which do not, of course, destroy the value of the admission when finally obtained, but they affect the value of the expert, both to the cause and to the Court.

We can all imagine how provoking such answers are, particularly upon cross-examination. Nor do they do any good—they seem to be a sign of weakness, though they may not be such. Besides spinning out the record to an unreasonable length, and thus tending to irritate the judge who has to read the testimony, or wearying the jurors who have to listen, they add enormously to the expense, both in the way of fees for recording them and in the printer's bill, while the expert who gives such answers incurs the suspicion of trying to increase his own fees, as well as of being unfair. Of course I know that we lawyers, in our ignorance, often put questions that cannot be answered directly, and the expert in such cases is obliged to protect himself by necessary explanations; but it is better not to carry the matter too far, and often on cross-examination it is the best policy to answer "yes" or "no" whenever possible, as such answers do not provide the lawyer with material for his next question. Indeed, they are often the most embarrassing answers that can be given. Again, instead of giving explanations, it is frequently wise to answer "yes and no," where neither assent nor dissent alone would be sufficiently full, for then you put the responsibility of further inquiry into what is often a totally irrelevant subject upon the lawyer and he must take the blame. Besides, it is not necessary always to explain so much, for the judges are not always ignorant, and it must be your experience, as it is mine, that, as a general rule, justice is done in a case by the time, if not before, it has been decided by the highest court. We may not always approve the final decision, but in the great majority of cases it is apt to be right.

Then there are experts who have a special hobby, and who endeavor to bring everything around to that particular pet; and though they may not be quite so bad as a lawyer with whom I am acquainted, and of whom it was said that on one occasion, in addressing the Court, he remarked: "I do not know much of the subject of this case, but I do know something of electricity," (I wonder how much he knew), "and, if the Court please, I will say something of that,"yet they are apt to bring in irrelevant matter in exploiting their own " fads," and, possibly, their own reputations. Then, again, I remember an instance where an expert took seventeen days to answer one question. It is true that it was not entirely his fault, for he was asked by the lawyer who retained him to compare the invention of the patent in suit with each and every of the patents and publications set up in defense, and this, of course, required time. The expert was left alone with the typewriter, without questions to guide him as to what matters were important and what references might be quickly passed over. The proper way was for the lawyer and the expert to have consulted previously and decide which references were the most important, so that the others could be dismissed in a few words. The lawyer should have taken the burden of telling the Court why the references were not all material, and the Court would have understood.

There is another very important defect in the mental makeup of some experts, and that is a tendency to discuss and explain their interpretation of the law. I recall a very able expert whose inclination in this regard was so strong as to frequently interfere with his usefulness. He would not only dispute the matter with the lawyer who called him, but even when told that the United States Supreme Court had definitely decided the question contrary to his contention, he would reply that in that case the Supreme Court was in error. The dispute could generally be kept off the record while he was under direct examination, by a prior understanding with his retaining counsel, but he usually found some place for his views during the cross-examination. All this was wrong. The Judge paid no attention to him on this subject, and he only went out of his province to engender probable irritation and to cause undoubted unnecessary expense.

Now, having stated some of the qualities which an expert should not possess, let me pass to the other side of the picture and enumerate some of the privileges, rights, duties and characteristics which pertain to a competent expert. First as to his privileges.

I can conceive of no case where it is not the privilege of a qualified expert to testify, unless it may be because of his relations to the opposite side, and I shall speak of this subject later.

There is no inherent reason why an expert is disqualified from stating the facts within his knowledge because he thinks that his client has a bad or unjust case.

I cannot do better than to quote some remarks made by Dr. Johnson which Boswell has recorded as follows:

"We talked of the practice of the law. Sir William Forbes said he thought an honest lawyer should never undertake a cause which he was satisfied was not a just one. Sir, said Johnson, a lawyer has no business with the justice or the injustice of the cause which he undertakes, unless his client asks his opinion, and then he is bound to give it honestly. The justice or the injustice of the cause is to be decided by the Judge. Consider, sir, what is the purpose of courts of justice! It is that every man may have his cause fairly tried by men appointed to try causes. A lawyer is not to tell what he knows to be a lie; he is not to usurp the province of the jury and of the judge, and determine what shall be the effect of evidence, what shall be the result of legal argument. As it rarely happens that a man is fit to plead his own cause, lawyers are a class of the community who, by study and experience, have acquired the art and power of arranging evidence and of applying to the points at issue what the law has settled. A lawyer is to do for his client all that his client might fairly do for himself if he could. If by a large superiority of attention, of knowledge, of skill and a better method of communication, he has the advantage of his adversary, it is an advantage to which he is entitled. There must always be some advantage on one side or the other,and it is better that the advantage should be had by talents than by chance. If lawyers were to undertake no causes until they were sure they were just, a man might be precluded altogether from a trial of his claim, though were it judiciously examined, it might be found a very just claim."

I think that the foregoing statement is peculiarly applicable to an expert even if its truth can be questioned in regard to a lawyer, as Lord Eldon did question it on one occasion. For the expert is called upon simply to state facts, and his conclusions from those facts. He is not required to enlist mistaken sympathies in a bad cause by persuasive eloquence. He should not be a "sworn advocate," as he has on frequent occasions been justly called. He may present the facts in the manner most favorable for the side for which he testifies, but they must be facts and they must be stated so as not to mislead. Each expert must judge for himself in these cases.

Imagine a case of poisoning. Would an expert be justified in stating that he had found arsenic in the subject of an autopsy, and suppress the facts,either that it was in such minute quantities that it could not have been the cause of death, or in such portions of the cadaver as showed that it was injected in the embalming fluid? Would it be right for him to trust to the opposing lawyer to bring out such facts? Again, in the case of an engine, would it be right for an expert to say that it worked, but omit to state the fact that it would only run during an incomplete revolution, or that it ran so badly as to show that it was a failure? Still again, in an electrical case, would an expert be right in asserting his untried theory as a fact? I leave the answers of these questions to the experts.

I was asked this question by an expert a short time ago: "If I am retained in a case by a lawyer, and, after looking into it, find that I cannot take the position that he wishes me to take, am I entitled to keep my retainer as compensation for my labor of examination, and refuse to testify? Further, can I accept a retainer from the other side and testify for them?

This looks like a complicated question, but it seems to me that the answer is really simple.

I reply that an expert is certainly entitled to compensation for his labor in examining the questions in a case in which he is asked to testify, if he has to expend labor in such examination. Whether he shall keep the whole amount of the retainer which was given to him in the expectation that he would testify, depends upon the amount of the retainer, and the amount of labor necessarily expended in the preliminary examination of the subject. Although it is not always just to the expert, I think that the better policy would be to return a considerable part of the retainer and keep the rest as compensation. I know of one expert who used to return the whole of the retainer if he was unable to act, but he was a rich man and could afford to be generous. Even then, I believe that his practice tended to his advantage in the end.

The better way is to have an understanding in advance that a fixed sum is to be paid for the preliminary examination, making this sum large enough to compensate also for the expert's risk that such examination may disclose facts to him that would prevent him from testifying for the other side, even if he found that he could not act for the first applicant for his services, and, perhaps, a further sum as retainer, if he testifies.

The answer to the second part of the question is as follows:

If the expert has, during his preliminary examination, learned facts which can be even remotely said to be confidential and which are detrimental to the side for which he was asked to testify, he cannot in any case act for the opposite side, for he would be under a moral obligation to tell all that he knows that would assist the whole truth being elicited. If he has learned nothing which is of a confidential nature, I know of no reason why he should not testify for the other side.

The following question has also frequently arisen. An expert has testified in a case, or several cases, where it was necessary to learn much of the client's business, his machinery and processes. In a new suit between the client and a new antagonist or one of the old antagonists, he has not been retained by his old client for some reason, but the adversary seeks to retain him. Is he at liberty to accept?

I think the proper thing for the expert to do in such a case is to state the facts to his old client and offer him his services, and if they are declined, ask permission to act for the other side. This is not indelicate, and it is only fair. The client can be trusted to either retain him or give him that permission. If, however, he does neither, the expert must judge for himself. It is certainly not fair that he should be forever tied up because he has once acted for a client.

A celebrated lawyer once laid down this rule of action for himself.

"If I ever had any connection with a cause, I will never permit myself (when that connection is for any reason severed) to be engaged on the side of my former antagonist. Nor shall any change in the former aspect of the case induce me to regard it as a ground of exception. It is a poor apology for being on the other side, that the present is but the ghost of the former cause.

I think that that lawyer went a little, but very little, too far.

Now, a few words as to the duties of an expert. Some of these have necessarily been referred to above, but there are one or two others that may be mentioned. First and foremost of these I put honesty, unswerving honesty and truthfulness.

Honesty and truth to the client, honesty and truth to the lawyers, and honesty and truth to the Court. In no other way can a man secure the respect of others, and, more important still, his self-respect.

In this way he will not convey false or misleading impressions, he will not suppress a part of the truth, and he will not "pad out" a record for the sake of increasing his fees, will not waste time, nor will he lend his aid to any of these things. He will govern himself with equal strictness on direct examination and on cross-examination, and he will take a position the reverse of that of the man who said: "If the facts do not agree with me, so much the worse for the facts."

Again, these qualities will lead him to answer each question by itself as it is presented, and not concern himself with what he may have previously said in that or in other cases, or on other occasions. It is probable that he has made former mistakes, but they must be confessed without fear. No explanation by him will ever reconcile two *inconsistent* statement of *fact* so as to cause belief that both statements were correct. He may show that they are not inconsistent, if he can, but this should be done as briefly as possible. If they are inconsistent, it is his duty to confess it.

Another duty is to be fully qualified to speak authoritatively on his subject. It would be well for him to remember what a Judge once said to me in explaining why courts are so jealous in assuming jurisdiction of a case. "It is not," he said, "that the judges are attempting to shirk work, but every case involves personal or property rights, and unless the law clearly declares that it is his duty to do so, a conscientious judge always dislikes to assume the responsibility of curtailing the one or taking away the other."

It is the expert's duty to his client and his lawyer to show the same hesitation unless he is fully equipped for the case.

My opponent once lost a very important electrical case against the city of New York, so that he had to drop it before it went to Court, because his expert had not informed himself about what he had to testify before he went upon the stand. The expert explained to me afterwards that his client would not meet the expense, but he himself evidently did not see that he should have declined to act without this necessary knowledge, and that even if it could not be said that he was attempting to deceive the

Court as to his qualifications, he was certainly jeopardizing his client's interests. This is a clear illustration of the necessity of a fully qualified expert.

Again we can all appreciate the value of an answer which reads, "I know it because I have tried it," and how such an answer, even when given by a young expert, counterbalances all speculative answers made by much more celebrated men.

I recall a curious instance which shows the necessity for experiment. A young electrical expert was asked on cross-examination for an explanation of the action of a certain structure and he gave his answer, basing it on his general knowledge of what had been demonstrated by Faraday, but without having had an opportunity to prove his correctness by experiment. He was contradicted and even derided by the opposing and better-known expert, and yet subsequent experiment showed that he was right. But it was too late for that case, and the Judge probably gave more weight to the erroneous view of the better known man than to the other.

As has been said by a well-known writer: "In deciding between contradictory expert testimony, juries should consider the respective reasons, ability, knowledge and fairness of the experts. To judge according to their number or their fame would be unsafe. The wealthier litigants are generally those who employ the more numerous and the more expensive expert witnesses. But it is not always the wealthier litigant who is right in a controversy, nor always the more famous expert who is right in his opinion," (he might have added his facts). "The carefully digested views of a young and studious scientist may be often more nearly true than the more hastily formed opinion of a more experienced man." (Walker on Pats. 3rd Edit. 498.)

There are many matters in which the Court or jury is not competent to weigh the "reasons," "ability," and "knowledge" of experts, but it can always weigh their "fairness"; and the man who hesitates to speak before he has proof of what he says always outweighs the man who boldly asserts a thing without having such proof.

Once more, an expert's duty to the Court should govern his action toward the lawyer who retains him. As an expert's first duty is to the Court as the representative of justice, he must not allow any consideration to interefere with this duty. With this in mind, he will primarily wish the questions upon which he is to testify to be submitted to him in such a manner that he can formulate his own conclusions without unavoidable bias, and without persuasion. It is best that he should not know, if possible, whether he is to act for the complainant or for the defendant, and he will ask the lawyer not to suggest anything that will tend to influence his opinion before he has made his preliminary examination of the matter in dispute. It is, perhaps, too much to expect that the lawyer will not generally allow his zeal to suggest what he wishes, but I have known cases where this was not done, and we can all readily imagine the feeling of relief with which the experts then went on the stand and testified that their answers had not been influenced by any considerations other than their own independent thoughts. I am sorry to have to say that these occasions are rare, but there can be no doubt that they should be universal. If they were known to be such, I think that in a large preponderance of cases, there would be no "conflict of expert evidence."

The experts have this matter in their own hands, and it is not only their duty, but their right to see that the practice is general.

And now in conclusion, a few words as to the characteristics of a competent expert.

I am pleased to be able to state that in my experience I have rarely met with an expert who was other than courteous, modest, and tolerant in manner. They seem to have an innate perception of two valuable rules laid down by Vice-Chancellor Hoffman for the guidance of lawyers. The first of these is as follows:

"Should I attain to that eminent standing at the Bar which gives authority to my opinions, I shall endeavor in my intercourse with my junior brethren, to avoid the least display of it to their prejudice. I will strive never to forget the days of my youth, when I, too, was feeble in the law, and without standing. I will remember my then ambitious aspirations (though timid and modest), nearly blighted by the inconsiderate or rude and arrogant deportment of some of my seniors; and I will further remember that the vital spark of my early ambitions might have been wholly extinguished, and my hopes forever ruined, had not my own resolutions and a few generous acts of some others of my seniors raised me from my depression. To my juniors, therefore, I shall be ever kind and encouraging, and never too proud to recognize that, on many occasions it is quite probable that their knowledge may be more accurate than my own, and that they, with their limited reading and experience, have seen the matter more soundly than I, with my much reading and long experience."

We all readily see how this is as applicable to experts as it is to lawyers.

The second rule reads:

"Should judges, while on the bench, forget that as an officer of the court, I have rights and treat me even with disrespect, I shall value myself too highly to deal with them in like manner. A firm and temperate remonstrance is all that I will ever allow myself."

This may be paraphrased for experts as follows:

Should lawyers, while questioning me, forget that as a witness and a gentleman I have rights, and treat me even with disrespect, I shall value myself too highly to deal with them in like manner. A firm and temperate remonstrance is all that I will ever allow myself.

There is no doubt that occasions frequently arise when there is a strong temptation to turn foolish questions into ridicule, when a trifling advantage may seem to be gained by sarcasm or an unkind witticism, but this does not pay in the end. Front and foremost of all, the sacredness of the cause should be borne in mind; it is a serious matter that calls for expert evidence, and the expert should be serious. Jokes are very good fun, but unless they illustrate a point you wish to make, they are out of place in a court of justice.

I look forward to the time when the Court will have its own expert as its technical adviser, and then, while there may still be that "conflict of evidence" which is now so usual, it will do less harm. The Court and its expert will work together to arrive at the truth and sift the chaff from the wheat. I believe that this practice has been adopted in France and in Germany.

Finally, when I add that the competent expert tries to explain the most technical questions in the least technical way; that he is equipped with a wealth of illustrations to illuminate the facts; that he confines his answers as closely as possible to the questions; that he is not timid in admitting his ignorance; and, besides all this, is ingenious in devising models and experiments to explain his statements, I believe that I have enumerated most of the qualities which a competent expert should possess.

Discussion.

Mr. Edward P. Thompson:—I wish to make a few remarks on the experts' side of the question. In regard to the matter of honesty, of course that is an enormously important matter, and yet a comparatively trivial matter. There are plenty of people who are honest. What we want is more competency. That is a scarce article. I remember one expert saying that he did not like to be an expert. I said, "How is that? You have served very often." "Well, I don't like it. I find clients all expect me to tell lies, and I don't like to disappoint clients." But that same expert is one who was quite popular, and is the one whom lawyers prefer. He is both honest and competent. A person is the best expert who is not only honest but also competent. You must keep those two things together. Honesty without competency amounts to nothing. Competency without honesty amounts to nothing. It is just like an invention,—a combination of two things. An expert must be a combination of these two things. In the first place, he ought to be able to distinguish between what is an invention and what is a device. Of course he must not hurt the feelings of the judge and the lawyers, and tell whether the device infringes or whether the two are identical; but the expert must *know.* He need not declare whether there is infringement or not, but that is what he should tend to understand from the time when he begins to examine the papers, to the end of the case; and if in examining, he is very doubtful as to whether his testimony will be beneficial to the client, he should tell the client that, and let the client know his honest opinion.

As to this matter of the value of an expert,—experts are witnesses. When cases can be carried on in court without witnesses, then patent suits can exist without experts.

On the subject of an expert being employed by the court, as a substitute for employment by the client, of course that would be worse than it is at the present time; but the suggestion as interpreted in another way, I fully agree with, and that is that in addition to the experts employed by the different parties there should also be an expert engaged by the court, because such an expert can greatly assist the judge. Otherwise the judge is in a state of confusion. I happened to be acquainted with a certain judge who decided a patent suit. He knew nothing about electricity. He knew no more about electricity than we are supposed to know about Greek—not as much. Such a judge cannot understand experts on opposite sides. He knows not which one to believe.

The expert has come to be, of course, a professional man. If there are fifty claims, experts must know what the difference is between the first and fifteenth, or the first and twentieth, and so on. They must know the exact shade of difference between those claims.

As to incompetent evidence there is an instance where testimony was given in the Morse case; they actually brought in as alleged *bona fide* evidence the fact that dots and dashes were scratched on the walls of a prison by two prisoners, who could not actually see each other, the dots and dashes representing the alphabet—that was submitted in a *bona fide* way into court to prove that that was anticipation of the Morse telegraph system. What is the difficulty, and why is there anything strange about this? There is really nothing unusual; it only happens to be an important case in the courts, and happens to be an important invention, and happens to be an important inventor, and so it strikes us as unique. Similar blunders occur now. An expert often distinguishes between the elements of an invention, instead of the invention as a whole. An invention consists of a combination. Laughing gas would not be old simply because its elements, nitrogen and oxygen are old. Testimony is wrongly taken in regard to priority of the *elements* of the invention instead of the invention itself as a combination. You have to distinguish what is an element and what is the whole invention.

In a certain patent suit, there was a photograph which apparently illustrated the same invention as the model that was put in by the other side, and was about to be accepted, and stipulated upon, that it would not be necessary to bring the model represented by the photograph,—that the two were identical. But the expert insisted upon having more satisfaction than that, because the photograph looked suspicious. A photograph, you know, can make a circle look like an ellipse, for example. It makes things in the background appear closer than they really are. The photograph had been taken to make the two things look alike and yet they were not. So the expert must know the tricks practiced by the other side. They may not be intentional tricks; you need not accuse a person of being dishonest, but things come up of that kind and if a person is not aware of what is going on, he may get caught himself.

The gentleman who read the paper spoke of one expert who took seventeen days to answer one question. Probably that was the fault of everybody, the fault of the expert and the fault of the lawyer and the fault of the stenographer and the fault of the opposing lawyer, and the fault of so many patents being put in, and faults all over. Everything was wrong. Of course the solution that was given by the author of the paper was the proper one.

Mr. Jesse M. Smith:—I think if we were to hear another lawyer on this same subject we would get very different views, just as different experts will have different views on the same subject. If there were not two views by different attorneys, and two views by different experts, on a given subject, there would be no litigation—there could be none. Now it is the function of the court to determine which of these two opinions is more nearly reasonable, which is right, as the court sees it; because the court is the one authority that can cut the "Gordian knot". It is not for the experts, nor for the attorneys. The first court may be wrong, but then the case will go to the appellate court, and two appellate courts may see it differently. Then the Supreme Court of the United States comes in and says what is right and what is wrong, and nobody can go behind that.

Now as to what the duties of an expert are, and what the duties of an attorney are in a case. That is a question which is also debatable and which will be debatable to the end of time.

On the question of whether the expert should sit with the judge, or whether the facts can be brought out better by experts hired by the two sides, I lean to the idea of the experts hired by each side, and let those experts be honest and competent, and let them sift the facts, each one presenting his facts as he sees them, to the best advantage; and let the court decide which is right and which is wrong.

Now as to the question of bringing an expert into a case without preparation. It frequently happens. The client has not money enough to pay, or will not pay the expert to properly investigate the subject before he goes into the case. The honest and competent expert will not go into a case unless he has prepared himself in advance; and he is entitled to the pay that is necessary for that preparation; and if after he has fully examined the case he says to his client, "I am not prepared to take the position that your attorney wishes me to take," then he should keep his retainer, and be paid something besides; because he has taken the confidence of the client, as well as the attorney who has put the papers and the facts into his hands, and he is in duty bound not to take the other side of the case under any circumstances. Therefore he is entitled to the full amount of that retainer and he is entitled to compensation for every hour that he has put on to the case, because he has done it honestly. He has earned it. I fully agree with the view expressed by Mr. Hyde, quoting from an eminent attorney, that when he has been once on one side of a case he cannot go onto the other side. It makes no difference whether his client has failed to retain him on a yearly retainer, or in any other way; if he has once taken the confidence of a client he is bound by common honesty to stand by that side, and not take a retainer on the other side, and risk breaking down his former client's case, by divulging some secret or confidential knowledge.

Now in regard to this question of a man taking seventeen days to answer a question. That applies to me.

Mr. Hyde:—I think not. You are not the gentleman I referred to at all.

Mr. Smith:—I am going to say that it applies to me because I have frequently taken that amount of time to answer a single question, and I expect to continue in just that way, and I will tell you the reason why. In the majority of cases in which I have testified, for the most competent attorneys in this country, I have rarely been asked on direct examination more than six questions. The first one, " What is your name, age, residence and occupation?" The second, " What is your qualification?" The third, is some insignificant question. Then come the crucial questions: Fourth, " What is the structure set forth in the patent in suit and recited in claims 1, 3 and 5?" Fifth, " What is the state of the art in regard to those claims?" Sixth, " Compare the patent in suit with the state of the art." Now those questions sometimes are condensed into two or three, and with design. It is done, where a competent attorney and a competent expert come together, after a very careful study of the case by the expert, and a very careful consultation between the expert and the attorney, so that the expert knows exactly the position which the attorney takes, and the attorney knows exactly the position which the expert takes, and they are working in unison. When that is so, all that is necessary is a single question to bring out the facts in regard to the case. .Then another question is, " Compare the patent in suit with defendant's structure." This question may take several days to answer, in connection with the prior art; but when those questions are asked and answered the direct testimony is finished. Then comes in the cross-examination, and that takes longer.

As to the question whether two men can be honest and be of different views on the same subject: I was in a case recently where the question turned upon whether a rheostat was an electric heater; that is, whether a rheostat could be cited properly against a patent for an electric heater. A coil of wire in which a current of electricity is passing is a rheostat, and it is also a heater. Now where does the coil of wire cease being a rheostat and begin to be a heater? You cannot put a current through a coil without having resistance, and you cannot put a current through the same coil without getting heat. Therefore a rheostat is a heater. But experts will talk at length on that little difference. They will say that a rheostat cannot be cited against an electric heater patent, and *vice versa;* and in that way a large amount of time is lost and a large amount of money is wasted, in talking about insignificant facts, when it is simply an application of Ohm's law.

It is said by the author, and very properly, that an expert should not get mad, should not say things on the record that do not belong there. I perfectly agree with him. He ought not to get mad, but it takes a saint not to get mad at the questions that are sometimes put to him. The expert who has had the most experience gets the least mad; but he gets awfully mad in getting the experience. Sometimes, after a long direct examination, the first thing that the attorney on the other side does is to put in a lot of objections, in which he attacks the honesty of the witness, his ability and his sincerity, and suggests everything that is disreputable; and it is done evidently with the intention of getting at cross purposes with the witness from the beginning, and getting him mad and getting him to say things that he would not say in his sober senses. It is necessary sometimes to know the tricks of the attorney for the other side in order to meet them. An expert is liable to confront some attorneys (fortunately there are very few of them) who are dishonest enough to pursue that kind of a policy; but I wish to say here, that in all my experience with the patent bar, not only in this city but in the West, where I have had more experience than here, a finer set of high-grade gentlemen does not exist than the better practitioners of the patent bar.

MR. CHARLES L. CLARKE:—As the author says, the public derides expert testimony. Naturally there is considerable dissatisfaction with such testimony on the part of lawyers, and experts themselves are disgruntled more or less, because of this state of of affairs. I think whatever disfavor experts meet with is, in greater part, due to themselves. It makes no difference what pressure may be brought to bear from the outside to mislead an expert, or to induce him to depart from telling the truth and telling it straight, whether in matter of fees, or zealousness for clients, or the prodding of lawyers, an expert is not obliged to be governed thereby, if it does not lead him in the line of truth; and if he does not follow in that line, of course he injures his reputation. An expert ought to be upon a very high plane, practically upon the same plane as the court, only the expert does not decide the case. Therefore, when an expert does fall, the fall is great, and the noise that is made thereby is loud and spreads afar. A very few experts who do not go just right can bring discredit upon the whole craft.

I was impressed with the correctness and importance of that part of Mr. Hyde's paper in which he speaks about the improper tendency of some experts to discuss and explain, in testifying, their interpretation of the law. In that connection I would say that we experts sometimes do, so to speak, take the law into our own hands. I have done it. I am getting over the bad and improper habit, or at least trying to, of expressing opinions upon the question of invention. Quite frequently that habit on the part of experts has been severely criticized by the court. Of course an expert has no right to express an opinion as to whether to do a thing did or did not require invention; that is a question solely for the court to consider and decide. Then, again, experts are making an ever-increasing use of that mysterious and well-nigh omniscient individual, the "skilled mechanic", to help make out their client's side of the case. They very often express the opinion that the skilled mechanic would naturally, as a matter of course, have done this and that—the very thing described in the patent which is in suit—thereby practically testifying that no invention was required. It is not right for the expert to make any use of the skilled mechanic other than to cite all the cases that may be necessary as bearing upon the matters in controversy where mechanics have been known to do certain things. The expert may approach just as close to what has been done in the patent, by explaining what mechanics have done, as he possibly can. Then it should be left for the court to say whether, in view of what had been done, a mechanic would, without invention, have done the thing which is in the patent in suit.

In regard to the question of the employment of an expert, I am rather inclined to think, after a full consideration of that matter myself, and discussing it with a number of prominent lawyers, that the best way for an expert to prevent misunderstandings, and avoid possible loss of reputation, perhaps unjustly, is to charge a reasonable retainer to cover a preliminary examination of the case, which retainer estops him from acting for the opponent of the party first approaching and retaining him, and is sufficient, in some measure, to reimburse him for the labor of such examination in case it is found that he cannot be of practical use to the party who has retained him. In that way he gets something for his work. Of course he runs the possible risk of being deprived of a large amount of work by not acting for the other party, in case he finds that is the party in whose case he believes; but nevertheless he had better lose that chance rather than run the risk of losing his reputation for fair dealing by accepting a retainer from the party who first approached him, and getting more or less knowledge of their secrets, and then going over to the other side. I am glad to see that the author agrees with me in this view.

Mr. Hyde has suggested the advisability of the court having its own technical adviser. I also think it might be well for the court to have such an adviser, but I do not think that the litigants should be debarred from having their own experts, because the court might not select a person who would be as competent to expound the technical and scientific features of the case as other available persons known to the lawyers of the litigants, and therefore an injustice might be done, although undoubtedly the expert adviser of the court would always be competent to review the testimony of the experts for the litigants. I think that the employment of a court adviser might tend to shorten the time consumed in taking testimony, and help to lessen expenses. Would it not be the fact that experts for litigants, knowing that an expert appointed by the court was to review their testimony, would be shorter, sharper, and more direct, and not wander off into the fields of conjecture? And then again would not the lawyers trim the case down, in view of that very fact, and not lumber the record with unnecessary depositions and other irrelevant matter?

In conclusion I might say that lawyers can assist in raising the standing of the craft by relegating to the rear experts who are known to be *shifty* and *adroit*, in the invidious sense of those terms.

We have with us this evening a gentleman who is known to you all, at least by reputation, as an expert of long experience and honorable standing, and from whom I am sure you would like to hear a few simple and direct rules for your guidance. He is, I believe, the Nestor of experts. It gives me pleasure to introduce Mr. Edward S. Renwick.

MR. EDWARD S. RENWICK:—I was asked to come here this evening to listen to an address by Mr. Hyde, and came and have heard it with great pleasure. The paper is so thorough and exhaustive that it is difficult for me to add anything on the subject; but I may say a few words, and from my long experience, running back to the year 1850, and having been engaged probably in a greater number of cases than any man who ever lived, it may possibly be of advantage to those who are now here. I may say from my own experience that the first requisite of an expert, in my opinion, is absolute honesty. He must be honest not only in stating his opinion, but it is his duty to be honest in answering whatever questions may be put to him as directly as possible, even when those questions which are put to him may, in his view, militate against the side by which he is employed. You will find invariably that unless he does that, his own opinion becomes of less and less value the longer he continues in that course. There is no reason why he should not answer questions in a straightforward way, because if he does not answer them, somebody else certainly will, and if it is a fact that is important in the case it will infallibly come out, and the very fact that he has in any way avoided a proper answer will militate against the value of his opinion as to other facts. I recollect well a case in which I was employed with another expert; when a hypothetical question was put to him, as to whether a certain hypothetical machine would or would not infringe the claim of the patent. He wished to avoid the question, and when the question was repeated to him in a number of ways, a number of differerent times, he avoided an answer. When lunch time came I said to him, "Why on earth didn't you answer directly? It is plain enough." Said he, "Do you suppose they have got such a machine on the other side, and it is old?" I said, "What matter does it make? There is no question about the fact. You know as well as I do that such a machine would involve the patent and you may as well answer it directly. And," I said, "aside from that, there is not one chance in a thousand that they have got such a machine as an anticipation." So immediately after lunch, when the question was put to him in a different way, he answered it directly. Subsequently it turned out that no such old machine had existed.

There is another matter which I think is very important for an expert, and that is that he should thoroughly study his case. It is impossible for an expert to study his case too thoroughly; and unless he goes into the case with a thorough knowledge of every part of the specification, and how each part of it may affect the construction which must be put upon the language of the claims, he is not really thoroughly competent to be examined as an expert in the case. I have known many experts in my time, and I have known a number who relied upon their quickness, as they thought, when they entered into the case, in learning everything that was necessary; and that they would know more than the lawyer on the opposite side, and perhaps more than the expert on the opposite side; and that they could go on with the case without a thorough study of it beforehand; and I have never known a case where such a man succeeded. He went on for a few years and then was dropped.

There was one matter spoken of by Mr. Hyde upon which I do not exactly agree with him, and that is whether an expert who has been engaged by one party and who is unable to act for that party, can be employed for the opposite party. I think it highly improper that he should do so in that case. Another case may come up in which the circumstances are entirely different, and in which he might act; but in that case he certainly cannot act, and he cannot act in any case in which the grounds, the conditions, are exactly the same; because although he may think to himself that he can keep a straight path between what is right and what is wrong, it is hardly possible in human nature to do so, and the better course is to refuse to act for the opposite party.

There are some other questions on which I might perhaps say a word. As to the question of an expert being called by the court; however an expert may be employed by the court, or may become a member of a court, it would not be possible for him to thoroughly understand the case, unless he had the views of the other experts on the subject. An expert usually does not, in one sense make the case, but he stirs up the case so that you are able to get at the truth, and the stirring up of the case is best done by having two discuss the matter on opposite sides. For more than twenty years I have had an opinion that an appellate court should be created at Washington for the purpose of trying appeals in patent cases, especially for the reason that now we have I think eight circuit courts without any appeal from them; and we have cases already in which in the different circuits the courts have come to exactly different opinions. Before the present system, we did have in the Supreme Court a court of last appeal. We ought now to have an appellate court sitting at Washington for special appeals in patent cases; and in such a court, I have always contended that an expert should be a member of the court for the purpose of instructing the court confidentially; for the court cannot possibly call on the experts of either of the opposite sides for that purpose, because the expert on one side might be biased in one direction and the expert on the opposite side in the other; therefore I think if such an appellate court is created an expert should form a member of the court. In the State of New Jersey, in which I live, we have courts composed in part of lawyers and in part of laymen. While the lawyers as a general rule overrule the laymen, there have been cases where the laymen overruled the lawyers. There have been cases where the laymen were right and the lawyers were wrong. It might be the same in patent cases. There is one other matter, and that is with reference to experts testifying on opposite sides. Two honest experts may in a patent case testify honestly directly opposite to each other, the reason being this: that in every case the opinion of an expert is based upon his understanding of the invention. Now two persons having opposite characters of mind may form two different views of an invention, and may honestly do so; and there is no reason under such circumstances why each expert may not be thoroughly honest and may not testify honestly. It is the duty of the court in that case to determine which particular view of the experts is the proper one.

As to an expert giving his own views of the law in a case, there is no doubt about the fact that it is the duty of an expert to express no such view unless he is called upon. I regret to say I have in some cases been called upon by lawyers to express a view on the law in a case, but it has been a very rare circumstance, and I never volunteered it in my life.

Experts have been known to take without study the view of the patented invention formed by the counsel in the case. I have known some experts who were engaged by counsel for the reason that they were ready to take any view of the invention which the counsel thought expedient to win the case; and I have seen such experts fail on cross-examination and get out of the business in a few years. I have had counsel ask for my understanding of a case after I have studied it; and, when he found that it was unfavorable to his client, to say, "the exigencies of this case require" a different view, which I knew I could not conscientiously maintain. In such a case I have said that he must find some other expert, and have not been called upon to testify. Subsequently I have learned that the counsel found no difficulty in getting an expert who would testify as the counsel wished, without regard to any opinion that the expert might form upon a study of the case. Such experts must have had the happy faculty of believing that the party on whose behalf they were engaged was always right, a condition of mind that was impossible with me.

MR. CLIFFORD E. DUNN:—Mr. Hyde has certainly given us a very interesting paper on the rights, duties and characteristics of an expert. In view of the fact that he has had so much more experience at the bar than I have, I am somewhat backward in saying anything which would seem to be contrary to his expressed views, but there is one matter which, it appears to me, he has not taken into consideration at all. The paper consists of practically two parts: first, a statement of the present conditions, and a concession that they should be better; and, second, the way of producing that betterment; and it seems to me the two tend to an idealization of the expert. Now let us see what these present conditions are. Our procedure in a patent suit is to first file our pleadings, get those straight; then the complainant proceeds to take his testimony. He gets his expert witnesses and they testify to the scientific facts, and their deductions from them; and then those facts are almost invariably contradicted by the expert witnesses on the other side. The records are printed and together with the briefs of the opposing counsel are submitted to one of the circuit court judges. Now who is this circuit court judge? In nearly every case he is an able lawyer, but in nine cases out of ten, I think I can safely say, he is a man who has practically no scientific knowledge whatsoever, and this is so for very obvious reasons. Circuit court judges are chosen for their legal qualifications, not for their scientific, as the patent cases tried before them represent but a small portion of their work.

Notwithstanding that, many of these cases involve questions of the most intricate kind. One case which Mr. Hyde mentioned, Tesla *v.* Scott, involving three or four of the Tesla alternating-current motor patents, was decided by Judge McPherson, of Pennsylvania, a few months ago. Judge McPherson before hearing the case admitted that he was ignorant of what to us seems to be an elementary fact, that a current passing through a coil of wire surrounding an iron bar makes the bar a magnet. One of the most elementary principles of electricity he knew nothing of. Yet he was called upon to decide the right to the inventions shown in those patents. Is it any wonder that he, in his opinion, quotes the complainant's brief almost word for word, and then modestly says that he advances the opinion for what it might be worth? It seems to me that the remedy for present conditions is not wholly within the scope of the experts themselves. They are called upon to state their understanding of certain scientific facts and their deductions from them. As Mr. Hyde says, they present them in the most favorable light for their client. That is only too true, and is it reasonable to suppose that a layman can go to work and sift these dissertations, dealing with the most abstruse questions, and find the real wheat and discard the chaff in every case? I think it hardly likely. Mr. Hyde leads up to the statement, or the inference which I drew from his paper is, that by experts increasing their honesty—I prefer to call it frankness—their present unsatisfactory standing will be bettered to a certain extent. There is a very obvious argument against that proposition, it seems to me. We will assume that the body of experts are raised to this ideal plane of perfect frankness; a suit is brought, and the defendant or the complainant comes to an expert and seeks to employ him. The expert looks into the case and finds some weak points. The employer must assume that when the expert goes on the stand he will be perfectly frank and deal frankly with those individual points; and it is all right that he should do so; but is it human nature that a litigant who has probably been forced into litigation, and, although he may have the wrong end of the case, be bound to carry it through—is it human nature that he is going to employ a man to help him lose his case by explaining its weak points? It does not seem so to me. There are two ways, both of which have been already mentioned this evening, of getting around the difficulty. One is the method of having a court expert to oversee the transactions, and to confer with the judge, still having the experts employed by the litigants. The other is the system which is now in use in Germany, but which I think less favorably of than the other one. Over there the litigants file their pleadings substantially as they do here, except that they are much more full; details of infringement, and such things, are given. Three sets of questions concerning the matters at issue are then drawn up, one set by each attorney and another set by the court. These three sets of questions and the pleadings are submitted to the two experts selected by the court, who have no knowledge as to who the parties are, and these experts render their opinion on the questions at issue. Then it seems that their opinions are in turn referred to another expert, also appointed by the court, and also ignorant of the particulars of the litigation; who, in conjunction with the court, renders the final decision. And I have been told by an expert here in this city that a very curious result has grown out of that. Some cases over there are of such wide notoriety that the expe ts when made acquainted with the facts could not help knowing who the litigants were. To prevent that they have sent those questions for decision to experts in foreign countries: and I understand one expert in this city has had some of those cases for final hearing before him. He renders his opinion and sends it to the court.

MR. ELIAS E. RIES:—There were several interesting questions brought up and partially answered in the paper of Mr. Hyde, and in the discussion following. There is, I believe, a better remedy which suggested itself to me, and one that might possibly overcome the difficulties that have been cited. Presumably, of course, the object of expert testimony is to get at the truth, the exact truth, of the situation on the technical side of the questions involved. That this object is not always attained is obvious from what has been said here to-night. It stands to reason that there must be, assuming the entire honesty of the experts, numbers of instances where the expert can decide with equal facility and without any pricking of his conscience, on either side of the question at issue with equal truth. For example, we have had a case cited this evening involving the difference between a rheostat and a heater; that is to say, at what point a rheostat became a heater; and there are any number of questions of similar delicacy, differing only in matters of degree and often to a very slight extent, which, under existing practice, are quite naturally dwelt upon and defined by experts in favor of the side which employs and pays them for their services. Now, in contradistinction to current practice, I believe it would be possible and quite feasible to provide a plan whereby each litigant shall have the right to nominate his own expert, that is to say, to select some expert whom he believes to be best qualified, by reason of his familiarity with the art, or of his special knowledge of the matter involved, to decide the questions in the case which pertain to his particular patent, or who is familiar with the questions involved to a greater extent than some other expert might be. This much being accomplished, have it arranged that the pay of those experts shall be jointly borne by both litigants, or charged to the costs of the suit; that is to say, let it be understood that the experts are not so much in the employ of the litigants themselves as in the employ of the court, since it is their purpose to so answer questions as to bring out the truth. Then, if deemed desirable, let the court itself appoint an expert, or rather let the two experts of the litigants appoint one, who will act as umpire. There would thus be a sort of board of arbitration of experts, two of whom nominally represent the litigants in the case, and these two selecting a third, who will pass finally upon any undetermined or disputed question that may come up, and who will report to the court itself. In that way, an expert, knowing that he is directly responsible to the court, will in nine cases out of ten seek to do justice; that is, he is perfectly free to act in the interest of pure truth, and will have no motive in twisting or straining technical points in favor of one side or the other against his unbiased judgment. It seems to me that a plan of that sort would be advisable and conducive to quicker, more expeditious and more equitable results than are obtained by the present system of paid experts on both sides.

MR. WM. MAVER, JR.:—We have all been much interested in hearing Mr. Hyde's paper and in my mind there is no doubt as to the lasting value of this paper.

It may at first be thought that inasmuch as the number of electrical experts who now make a specialty of testifying before the courts is comparatively limited, therefore, the paper may not apply directly to a very large number of persons. It is also probable that the number of such specialists may gradually diminish because of the diminishing demand for their services; owing largely to the fact that in many cases the differences between the lions, and the lions and the lamb, which accrued to the benefit of the expert, do not now so frequently occur, the lion and the lamb having settled many of their differences and now lying down together; the lamb usually inside the lion. But, of course, there will always be a greater or less demand for the specialist, and to him the suggestions in Mr. Hyde's paper will be very welcome. Furthermore, it is very rarely that at some time in his experience the regular electrical engineer is not called upon to testify as an expert, and to him the points in Mr. Hyde's paper will be, I might say, invaluable.

I should like to say briefly something on the side of the expert with regard to some of the points mentioned in the paper.

With reference to the bias of ratio of fees to services. It is, I think, doubtful if one expert in a dozen gives the question of his fee a moment's consideration while he is studying the question at issue or while testifying. The natural expert is, so to speak, a soldier of fortune (not a "mercenary"), and his only thought while he is testifying is to protect and advance his client's interests and also incidentally it may be to enhance his own reputation. I do not for a moment imply that before and after his direct work in a case, the question of fees is neglected by the expert. I have myself handed large fees, for services rendered, to some noted experts, and the fees were received without visible signs of compunction.

From personal observation I quite agree with Mr. Hyde, that in the great majority of cases justice is done in a case, finally.

Mr. Hyde advises the expert to give categorical answers to questions so far as possible, and thinks that an expert should answer each question by itself as it is presented, and not concern himself with what he may have previously said in that or other cases. If the expert were sure that the opposing lawyer would not take advantage of apparent inconsistencies, he might disregard previous statements, but that is too much to expect, I fear.

Mr. Hyde also appears to suggest that the expert should volunteer information that may be prejudicial to his own side, and asks if it would be right to say that an engine worked, but omit to say that it would only run an incomplete revolution. This is a case where an expert would most likely give the categorical answer which lawyers seem so much to desire. The next question would doubtless elicit the information as to the incomplete turn of the engine (unless the opposing lawyer were very derelict), the facts would thereby be brought out, and the expert would avoid the charge of having volunteered the unfavorable testimony; if it was unfavorable.

I recall an instance where an expert witness in a very important suit for infringement of a patent, while in the middle of his testimony in the case, discovered a hitherto unnoticed action in the apparatus concerned in the suit, which he believed would upset the most important contentions of his side, should the said action become known to his opponents. Would it be said that this was a case where the expert should have shared his newly acquired knowledge with his opponents, to the great injury of his own side. Yet it might be assumed from Mr. Hyde's remarks, if I do not misunderstand him, that strict honesty to the court would have required that the information should have been volunteered, regardless of the employer's interests. This is doubtless an instance where, as Mr. Hyde states, "each expert must judge for himself."

The occurrence of cases like this, however, emphasizes the need of experts for the court, who would by reason of their impartial connection with the case be of great utility in bringing out all the facts possible.

I fully agree with the author of the paper in respect to the value of testimony based upon personal, practical knowledge or experiment. I recall another instance in the case of a suit for damages in which it was seen from the drift of the complainant's case that the point would be made that if a copper wire of an arc-light circuit came in loose contact with the iron span wire of a trolley road and formed a "ground," it would be the copper wire, and not the iron wire, that would melt owing to the lower melting point of the copper. On consideration it was seen that there were three reasons why the iron should be the first to separate. Namely, the higher electrical resistance, the lower heat conductivity of iron, and the fact that the iron wire was sustaining two trolley wires, while the copper wire was hanging loosely from a pole on one side of the street to the lamp-post on the other. Before going on the witness stand the expert made tests which showed that under the conditions stated an iron wire would be the first to separate, and he was prepared to so state if the question as to actual knowledge had been put to him, but it was not necessary, the complainant's expert witness, under cross-examination, admitting that theoretically the iron wire would first separate.

I also quite agree with the author in his remarks concerning the temptation to turn unwise questions of an opposing counsel into ridicule, and that it is much better not to yield to this temptation. And also, where an opposing lawyer asks a question hurtful to his own case, not to harp too much upon it. It is fair to assume, as Mr. Hyde points out, that the court will be quite as acute as the witness to observe the slip. Not very long ago a question of this nature was put to myself, and in my answer I emphasized the slip in addition to giving an answer to all that the question called for. My cross-examiner had been studiously courteous throughout, and I felt that my superfluous remark was a poor return. By consent that portion of my answer was stricken from the record and, although no remarks were ex-changed off the record, it was evident that the act was appreciated.

In the discussion reference has been made to the length of time taken sometimes by experts to answer questions, and ten or more minutes was cited as an unnecessary time for deliberation upon a question. I have on more than one occasion taken longer time than that to deliberate on an answer, and if the same questions had been submitted to me outside of the case I should have taken several hours for consideration of them.

The fact is that experts are frequently called into a case, and are expected to testify on very short notice. Consequently, the time for the proper investigation of a complicated case is often very limited, and it therefore seems reasonable that a witness should be given time to consider his answer in all its bearings to a question that may have brought up an entirely new feature of the case. Furthermore, it is very likely that an expert frequently takes longer to frame his answer than to reach a conclusion as to the purport of his answer.

There is a matter to which I would call attention, namely, the employment of an expert to consult with counsel while he is cross-examining the experts of the other side. It has seemed to me on reading over testimony that the advice of an expert at certain times would bring out evidence from the opposing expert which otherwise must be brought out on direct examination by other experts.

It seems to me also, from personal observation, that the matter of recording expert evidence that is sometimes followed in trial cases, as in damage suits, should receive the attention of lawyers. The editing of this evidence is usually left to the court stenographer, with the not uncommon result that so far as any real utility of the evidence to the appellate judges is concerned, it might as well not have been given.

MR. HYDE:—In response to Mr. Thompson and Mr. Renwick, I regret that there should seem to be, as it appears, any ambiguity in the last paragraph but one of my paper. I said that I looked forward to the time when the court would have its own expert as an adviser, and while then there may still be that "conflict of evidence" which is now so usual, it will do less harm, meaning, of course, that the court's expert will guide the court between the views of the opposing experts. I thought that the words "conflict of evidence" clearly implied the employment of experts by the parties as now, and I certainly contemplated such employment. If, as assented to by Mr. Renwick, it would be a good thing for an appellate court to have its expert, it seems to me just as wise for the lower court to have one also.

With regard to some of the views expressed by the other gentlemen, I desire to call their attention to the fact that it seems useless to try to defend the present system, and the manner of testifying frequently employed by experts under that system. The courts and public attack the experts, with justice, and the remedy does not lie in a counter-attack on the judges, nor in a defense of the present system, but in an effort to reform that system and the conduct of the experts themselves. Other papers could, of course, be written on the evils of the system, and on the qualifications of the judges, but the subjects would not be germane to that of the present paper.

[The Executive Committee has authorized the incorporation in this discussion of the following communications received since adjournment by the author, and which are printed in the order of their dates.]

DISTRICT COURT OF THE UNITED STATES.
CHAMBERS OF THE JUDGE

Utica, N. Y., May 21, 1900.

MR. J. E. HINDON HYDE,

My Dear Sir :—I took pleasure in reading your paper on "Experts and Expert Evidence." I agree in the main with what you say. Your suggestion as to a technical adviser for the judges is theoretically correct, but as a practical proposition I deem the objections almost insurmountable. Perhaps some practice analogous to the "Trinity Masters" in admiralty might be adopted. Even in this country it frequently happens that admiralty judges, where a technical question of navigation is presented, invite some expert navigator to sit with them during the trial.

Considering the "expert" question solely in relation to patent causes I think the principal difficulty is in the manner such causes are tried. If they were tried before an officer having power to rule upon the evidence, it is safe to say that half the evidence now presented to the court would be excluded.

But here, again, we are met by an almost insurmountable barrier. With the present judicial force it will be simply impossible to change the present system. In the meantime the members of the bar can do much to remedy the evil. My own experience is that in at least half the causes no expert is necessary. Their advice is only needed in electrical and chemical cases and in cases involving intricate machines. Comparatively few of the causes presented to the courts are upon such patents. Any judge competent to hear a patent cause ought to be able to understand the simple improvements covered by a large majority of patents. It would also tend to shorten the record if counsel would agree not to call more than one expert on each side. I have in mind several cases where from four to five experts were called on a side, each one repeating in different language what was said by his predecessor and adding nothing whatever to the solution of the question presented. Perhaps a rule of the court limiting experts to one on each side, unless the court by a previous order permits a larger number to be called, would help in this direction.

While I am not sanguine enough to believe that the question can be settled satisfactorily for some time to come, I am confident that all intelligent discussion of the subject brings us nearer to the desired goal.

Thanking you for sending me the paper, I am

Very truly yours,

ALFRED C. COXE.

SUPREME COURT OF THE UNITED STATES.

Washington, May 29, 1900.

J. E. Hindon Hyde, Esq.,
120 Broadway, New York.

Dear Sir :—I have to acknowledge receipt of your letter of May 19th, enclosing a copy of a paper upon expert evidence.

My own experience leads me to believe that but little weight can be given to the mere statement of an expert, unless it be fortified by substantial reasons. In the majority of cases these reasons may be stated as well by counsel who are thoroughly informed of their case as by experts. In the trial of admiralty cases, in which I have had large experience, I never permitted experts to be sworn unless I requested it, but usually called upon two to sit with me upon the bench and give me their advice. These two I selected from men whom I knew to be acquainted with the subject, and their assistance was of great value. In patent cases experts are always sworn and are sometimes very useful, although I have always treated them as retained by the party producing them to make the best case they can for him. My own conviction is that it would be better for the court to select its own experts from whom an unbiased expression of opinion could be had. I do not mean to accuse experts of being intentionally unfair, but few men can avoid a natural bias toward the party calling them. There is a difficulty in having professional experts who are known to the public generally, and who would be apt to be approached by parties interested ; but if the judge were permitted to select his own experts in each case I think their opinions might become of great value.

Very truly yours,

H. B. Brown.

UNITED STATES CIRCUIT COURT.

Judge's Chambers.

New York City, July 27, 1900.

My Dear Mr. Hyde :—I have received your note suggesting comment by myself on the proposed change in the practice, whereby an expert might be selected as a technical adviser to the court to whom the judges could refer in technical matters. Of course, if this were done, and it became correct practice for the judge to rely upon him, it is quite possible that our work would be easier, and may be the decisions more uniform, since the mental processes of the single expert would be largely substituted for those of the several judges. In view, however, of the contradictions now found to exist between experts of the highest standing, I should think any great increase in accuracy would be problematical. However, if that be what the bar and the litigants would prefer, the proposed change is one to be favored, since they would be better satisfied with results—at least such is, of course, the expectation although it is not impossible that the defeated party would find much to criticize in the expert's recommendations.

I do not understand whether it is proposed to select one expert, who will advise as to dye-stuff compounds, steam engines, sewing machines and electricity, or whether one is to be selected for each case. Speaking from my own standpoint, I am sure my own work would be much easier and in many instances—

perhaps in most instances—my opinions would be more nearly right, if in every complicated case I could turn for expert advice upon the conflicting technical evidence to some one who was to be accepted as an authority—*facile princeps*—in the art. If, however, the selection of such technical adviser rested with myself, the additional responsibility thereby entailed would add a new terror to the hearing of patent causes.

Upon the proposed suggestion, however, I stand entirely neutral; whatever will suit the bar will suit me; the personal equation is not to be considered.

I remain, faithfully yours,

E. Henry Lacombe.

UNITED STATES CIRCUIT COURT.
Judge's Chambers.

Cazenovia, N. Y., Aug. 1, 1900.

J. E. Hindon Hyde, Esq.,

Dear Mr. Hyde :—I have read with great interest and pleasure a copy of your admirable address on "Experts and Expert Evidence" which you have been kind enough to send to me. I am very decidedly favorable to the suggestion, made near its close, that the court should be permitted to have its own expert as a technical adviser, especially in the more complicated patent causes. The opinion of such an adviser upon the scope of claims and upon the question of infringements would be often of the greatest value. When experts are produced by the parties, the judges are not unlikely to regard their testimony merely as arguments under oath, where prepossessions and bias, or undue zeal, often generate erroneous conclusions. Indeed, much of the expert testimony which judges are called upon to read is largely or wholly disregarded. The most conscientious experts can, as lawyers generally do, convince themselves by their own arguments of the correctness of their positions. The conclusions of an expert selected by the court, or concurrently by the parties, for his qualifications in the particular case, would command genuine confidence, would largely control the decision of doubtful questions, and would relieve the court of great responsibility. I shall welcome the day when experts thus selected may supplement, if not supersede, the production of experts by the respective parties. Such an innovation would also be in the interests of economy and a speedier conduct of litigations.

Very truly yours,

Wm. J. Wallace.

UNITED STATES DISTRICT COURT—DISTRICT OF NEW JERSEY.
Judge's Chambers.

Newark, N. J., Sept. 15, 1900.

My Dear Mr. Hyde :—I have often felt the need of expert aid in the consideration of patent suits, but those selected by the parties are generally able to make the subject sufficiently clear to enable the judge to form a judgment. Of course, in selecting an expert to "sit with him at the hearing," the judge would choose one in whose ability he had the greatest confidence.

I would be afraid that the judge would be apt to place so much reliance upon the conclusions of his expert that the judgment ordered would in many, if not most of the cases, be that of the expert and not of the court.

Yours very truly,

Andrew Kirkpatrick.

The Chairman :—If there is no more discussion we will listen to the report of the tellers.

Mr. Mailloux :—The tellers will make an informal statement inside of half an hour, and shortly after that a full statement.

[Recess for half an hour.]

The Chairman :—The meeting will please come to order. We will hear from the Committee on Proxies, Mr. Mailloux, Chairman.

Mr. Mailloux :—We have met and counted the proxies and find that a total of 184 proxies have been sent in, all of which are held by persons present, with the exception of about 27, which leaves 157 net proxies present, besides the persons actually present. It was not possible to count the total number of persons present, but I presume there must have been 40 or 50, which would bring the total number of persons present and voting to nearly 200, that being a sufficient number for a legal quorum.

The Secretary :—I move that the report be accepted.

[Seconded and carried.]

The Secretary —Mr. Chairman, I wish to present, in accordance with Article 8 of the Constitution, a written proposal for an amendment, presented by Mr. Ralph L. Montagu, of Montana.

> "This Constitution may be amended by a two-thirds vote of the Members and Associates of the Institute : A copy of the proposed amendment is to be mailed to each Member and Associate, together with a blank ballot "For" or "Against". The blank ballot, after being filled in, to be returned to the Secretary of the Institute.
>
> "On the day appointed these ballots are to be counted, and if a two-thirds vote of the total members do not vote for the proposed amendment it shall be defeated, and it shall not be lawful to put the amendment before the members again until one year has elapsed, since the previous proposal."

Mr. Steinmetz :—I move to transfer this amendment to the Committee on change of Constitution, which was selected some time ago and is considering a revision of the Constitution.

[Seconded and carried.]

The Chairman :—We will now hear from the tellers of election, Mr. Wolcott.

TELLERS' REPORT.

Annual Election May 15th, 1900.

FOR PRESIDENT.

Total Number of Votes Cast........576.

Carl Hering	381	C. S. Bradley	6
M. I. Pupin	179	L. B. Stillwell	2
C. P. Steinmetz	7	T. D. Lockwood	1

Total..............576

FOR VICE-PRESIDENTS.

Total Number of Votes Cast...........1723.

G. S. Dunn	544	Louis Bell	1
A. V. Abbott	589	Charles Blizard	1
W. L R. Emmet	526	H S. Carhart	1
F. A. C. Perrine	12	C. C. Chesney	1
C. O. Mailloux	11	O. T. Crosby	1
C. S. Bradley	9	Charles R. Cross	1
D. C. Jackson	6	Alex Dow	1
Herbert Lloyd	6	I. H. Farnham	1
B. J. Arnold	5	Charles Hewitt	1
J. J. Carty	5	E. E. Higgins	1
W. J. Hammer	5	J. P. Jackson	1
Carl Hering	5	F. W. Jones	1
C. L. Edgar	4	A. E Kennelly	1
C. P. Steinmetz	4	T. C. Martin	1
M. I. Pupin	3	Wm. Maver, Jr	1
C. W. Rice	3	W. L. Puffer	1
H. L. Webb	3	Samuel Sheldon	1
F. B. Crocker	2	L. B. Stillwell	1
W. E. Goldsborough	2	C. A. Terry	1
F. A. Pickernell	2	W. D. Weaver	1
A. L. Rohrer	2	S. S. Wheeler	1
H. J. Ryan	2	J. G. White	1
F. Bedell	1		

Total.............................1723.

FOR MANAGERS.

Total Number of Votes Cast..........2294.

W S. Barstow	553	J. I. Ayer	1
R. D. Mershon	580	F. B. Badt	1
Calvin W. Rice	584	J. B. Cahoon	1
C. T. Hutchinson	319	H. B. Coho	1
J. J Carty	261	C. D. Crandall	1
T. Wolcott	19	Alex Dow	1
R. B. Owens	6	J. J. Flather	1
William Stanley	6	W. E. Goldsborough	1
B. J. Arnold	4	W. S. Hadaway	1
J. B. Blood	4	C. D. Haskins	1
Charles Cuttriss	4	F. V. Henshaw	1
E. J. Berg	3	Carl Hering	1
A. E. Kennelly	3	J. W. Howell	1
T. C. Martin	3	W. J. Jenks	1
F. A. C. Perrine	3	P. M. Lincoln	1
H. F. Albright	2	R. T. Lozier	1
F. W. Darlington	2	S. G. McMeen	1
William J. Hammer	2	F. S. Pearson	1
D. C. Jackson	2	C. W. Pike	1
H. W. Leonard	2	A. E Merrill	1
C. P. Mattthews	2	Thorburn Reid	1
William Maver, Jr	2	Jos. Wetzler	1
A. L. Riker	2	J. G. White	1
A. H. Armstrong	1	A. J. Wurts	1
W. S. Andrews	1		

Total..............................2294.

FOR SECRETARY.

Total Number of Votes Cast..........576.

Ralph W. Pope	573	C. T. Hutchinson	1
G. S. Dunn	1	Thorburn Reid	1

Total..............................576

FOR TREASURER.

Total Number of Votes Cast..........576.

George A. Hamilton	576

The total number of voting envelopes handed to the tellers by the Secretary was 666. Of these there were rejected 51, as follows: Unidentified 24, duplicates 25, one vote by proxy (ruled out by Chairman), and one vote of a member whose resignation had already taken effect. In the case of duplicates the one bearing earlier date was rejected according to the established custom of the Institute. This left 615 envelopes to be opened. After opening these, 32 ballots were found to be loose and unenclosed in any inner envelope, and in seven more the inner envelope was signed by the voter. These 39 were also rejected according to the established custom of the Institute, leaving 576 ballots to be counted.

Respectfully submitted,
TOWNSEND WOLCOTT,
SAMUEL REBER,
Tellers.

On motion, duly seconded, a vote of thanks was given to the tellers for their laborious task in counting the ballots.

[Adjourned.]

DIED.

Hudson:—At Beverly Farms, Mass., October 1, 1900, John E. Hudson, President of the American Bell Telephone Company. Mr. Hudson was stricken by heart disease at the railway station, where accompanied by his wife he was awaiting a train for Boston. Mr. Hudson was born in Lynn, Mass., August 8, 1839. He graduated from Harvard in 1862, remaining a tutor of Greek for a year, and after completing his course in the Law School began practice in Boston. After being retained as General Counsel in 1880, he was elected Vice-President of the American Bell Telephone Company in 1887, and two years later became President. He was elected an Associate Member of the American Institute of Electrical Engineers, December 20, 1893.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

SEVENTEENTH GENERAL MEETING.

PHILADELPHIA, May 16, 17 and 18, 1900.

The opening session of the Seventeenth General Meeting was called to order in the Drexel Institute, on Wednesday May 16, at 2 P. M., by Past-President Kennelly.

PAST-PRESIDENT KENNELLY:—The meeting will please come to order. The Secretary has an announcement to make.

THE SECRETARY:—Most of the members present are aware that the counting of the ballots for the annual election took place last evening at New York. The number of ballots cast was unusually large, amounting to over 600. I have this memorandum from the tellers of the vote for President:

New York, May 15, 1900.

The result of the ballot for President of the American Institute of Electrical Engineers is as follows.

Carl Hering	381
M. I. Pupin,	179

Mr. Hering received the largest number of votes and is elected.

Signed, TOWNSEND WOLCOTT and SAMUEL REBER, *Tellers.*

DR. KENNELLY:—Gentlemen, we have just heard that Mr. Hering has been elected President of the INSTITUTE by a majority of more than 200, and I think we may congratulate ourselves, as well as congratulate Mr. Hering upon this important announcement. I can only say I am delighted to resign in Mr. Hering's favor and it gives me very great pleasure indeed to appoint a committee to escort Mr. Hering to the Presidential chair. The committee will be Mr. Hammer and Professor Houston.

Mr. Hering, on being escorted to the chair, spoke as follows:

Gentlemen, I am very grateful to you for the honor you have conferred upon me and I hope that the officials which you have just elected will be able to conduct the affairs of the Institute to your satisfaction for the next year.

The meeting will now please come to order. The first thing on the programme will be an address by Dr. McAllister, President of the Drexel Institute, whose hospitality we are now enjoying. I take pleasure in introducing to you Dr. McAllister of the Drexel Institute.

Dr. McAllister spoke as follows:

Mr. President, and gentlemen of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS: I am very glad indeed, as President of the Drexel Institute, on behalf of the Board of Trustees to welcome you here to this meeting. I feel it to be a great honor as well as a privilege to have you with us. It is not worth my while to tell you the place which is occupied in our time by the profession of electrical engineering. I am in the habit of telling the students here that at the present hour there are two great leading professions. Those of us who were educated a generation ago or more, lived in a time when that profession hardly existed. There were the old-fashioned clerical, medical and legal professions, and that was about all. Nowadays the young man who has got the stuff in him, and the ambition, usually turns in other directions, and to my mind the two great professions to-day are the engineering profession and the architectural profession. Any one in my position knows it to be a fact—I used to talk with my friend General Walker about this—that the best young men to-day are pushing into these professions. There are many reasons for this, which of course occur to us all. Of all the engineering professions the electrical profession I think is the one which interests the mass of the people more, because it is one that is among the newest and most interesting and most marvellous applications of science to the arts of life, and has come to play a most important part in the civilization of the present, and will still more in the civilization of the future. We are very glad to have you here and I merely want to say to you that you are welcome to everything that we have. We would have liked to make some provision for your social enjoyment, but I understand through Professor Rowland, on behalf of the Committee of Arrangements, that your time will be wholly occupied in that regard. We have however, with the consent of the local committee arranged a complimentary organ recital for the members of the INSTITUTE and the ladies, on Friday afternoon at 3 o'clock, the programme of which will be distributed.

I presume most of you know very little about this institution, and entering it as you have, would be apt to get a false impression of it. I want to say to you that we think it is a fit place for an association of this kind to meet. It is an institution devoted to artistic, scientific and technical training, and is seeking in various new lines to work out the educational problem in the application of art and science to living. We have a very modern school of electrical engineering, different from the larger institutions, in some other cities, but where with a fair amount of scientific training and technical training there is a larger provision for practical work in the shop; and if you will take the trouble to go behind the screen—this external part of the institution—you will find the libraries and workshops I think well equipped for the purpose. For that reason we are glad to have you here. I trust you will not regard the presence of the students who choose to come here as any intrusion.

This is all I can say, to again repeat the cordial welcome of the Board of Trustees and of the Faculty of the Drexel Institute. We trust that you will enjoy your stay in Philadelphia. We are famous—well, for a good many things, but we are famous any way for our hospitality; we can take pleasure in that; we are very proud of that, and I think you will find yourselves as cordially welcomed here as you ever have been in any other city in which you have had the pleasure to meet. I beg again to give you a cordial welcome.

The President:—The Secretary has an announcement to make.

The Secretary:—You will find on the platform a bundle of notices giving a bulletin from the Franklin Institute, which includes a programme of the stated meeting of the Institute this evening, May 16, at 8 o'clock, to which we have been invited.

The following programme has been arranged: "Recent Improvements in the Manufacture of Liquid Air; the separation of air into its constituent parts, and the industrial use of oxygen, nitrogen, and carbon dioxide," by Professor Raoul Pictet and Moriz Burger.

The President:—In the absence of the Mayor of Philadelphia, who was to address us, we will proceed directly with the reading of the papers. The first paper on the programme is on "A New Transmission Dynamometer," by Prof. W. Elwell Goldsborough of Purdue University, who is already so well known to us through his work that he needs no further introduction.

A paper read at the 17th General Meeting of the American Institute of Electrical Engineers, Philadelphia, May 16, 1900, President Hering in the Chair.

A NEW TRANSMISSION DYNAMOMETER.

BY W. ELWELL GOLDSBOROUGH.

The dynamometer described in this paper is the outcome of a series of attempts to devise an instrument for the measurement of mechanical power comparable with electrical instruments as regards simplicity of design, ease of calibration, permanency of adjustment and the accuracy of the readings obtained. The dynamometer cannot be said to embody any radically new ideas. The principles upon which its success depends have been used in several other instruments; there is presented here simply a new adaptation of these principles. The instrument has been jointly developed by my assistant, Mr. E. T. Mug and myself.

The dynamometer, as shown in Figs. 1 and 2, is designed especially for testing electric motors of from five to 25 horse power capacity, and can only be used by directly connecting it between the driving element, the motor to be tested and the driven element, a dynamo, adjusted to absorb the power developed. It consists of a shaft, shown in Fig. 3, which is made in two parts. These are kept in line by having a portion of the left hand section turned down to exactly fit a concentric hole bored in the right hand section of the shaft. The joint presents a sufficient bearing surface to enable the instrument to stand quite severe lateral strains, although it is not sufficient to admit of the dynamometer being used to transmit power through the medium of belt-driven and driving pulleys attached to the outer ends of the shaft. For the dynamometer to be available for this class of work, the two sections of the shaft should be made in the form of quills to fit a second shaft extending completely through both sections.

Each section of the shaft is provided with a spiral grip-thread, turned to fit a spiral spring of $\frac{3}{4}''$ pitch. These threads are shown in the lower half of Fig. 3. The sections are also fitted with jaw collars, shown in the upper half of Fig. 3, that are turned to the same pitch. They have their spiral jaw surfaces cut to overhang the shaft, and make an angle of 45° with the shaft surface. The jaw collars, when forced into position by the lock nuts, with the aid of a spanner wrench, hold the end turns of the springs very securely, preventing them not only from slipping around the grip-thread, but also from springing out when the direction of rotation is such as to tend to unwind the spring.

All the spirals used with the dynamometer must have a pitch of ¾ inch, and be wound to snugly fit a shaft $2\frac{19}{32}$ inches in diameter. The jaw will securely hold springs from .2 inch to .6 inch in diameter, but necessarily the larger springs give a more stable adjustment and add stiffness to the instrument, considered as a transmitting device. Within the capacities of the springs, therefore, comparing them relatively to one another, the conditions for accurate work are more favorable with the larger springs. All the experimental work referred to here, however, was carried out with a spring made of standard No. 5 steel wire, which is slightly over .2 inch in diameter.

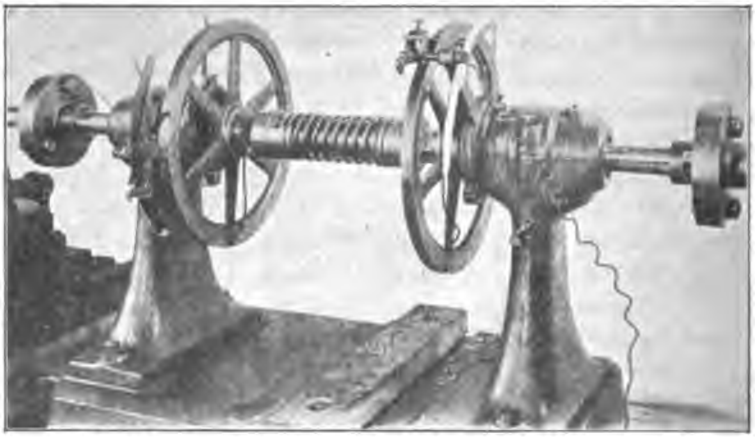


FIG. 1.

On the free sections of the shaft, shown between the hexagonal sections and the oil grooves, are mounted two instantaneous contact wheels, insulated from the shaft by hard fibre bushings. Each of these wheels, which are shown in Figs. 1 and 2, carries at its rim a contact edge made of sheet brass and set parallel to the shaft in a hard fibre plug, driven into an inverted V groove, and turned down flush with the surface of the wheel. The contact points are grounded on the shaft, and are therefore in electrical connection with one another, although insulated from the contact wheels. Two brush holders mounted on the dynamometer bearings, and carrying 90° graduated scales, supply the brush supports and complete the contact devices; they provide for the possibility of obtaining readings when the angular deflection of one wheel rim contact point is 180° from the other. The brushes are carried on insulated brush rods and are connected with one another through several primary cells and a telephone receiver, all in series. This adjustment supplies the means of detecting when the brushes are so placed that the contact points on the wheels pass under them at the same instant, since at such times a "click" is heard in the telephone at each revolution of the dynamometer shaft.

FIG. 2.

The description thus far given indicates with sufficient clearness the method of using the dynamometer and of obtaining instantaneous readings of the torque exerted by the driving element at any time. When, in the case illustrated, the motor is started up, the angular deflection between the contact points is increased above its initial value until the resistance to flexure offered by the spring overcomes the frictional resistance of the generator, and motion is imparted to its armature. If, by speeding up the motor or loading down the generator, conditions are varied so as to increase the resistance to motion between the two machines, there will be a still further deflection of the spring until the balance is restored between the forces acting. The variation in the angular deflection is quickly and easily followed by shifting the contact brushes until the "click" occurs in the telephone. In case the "click" is not sufficiently pronounced, a condenser, shown in Fig. 2, is connected in parallel with the telephone receiver, and its capacity adjusted until the "click" is sharp and clear cut. If ordinary conditions of constant load are maintained, such as are usual in any laboratory test, the "click" in the receiver will be kept up at a constant frequency, and the relative motion between the contact points will be zero, as shown by repeated trials, even when the smallest spring is used; and when a suitable tachometer is at hand, ideal conditions are presented for making instantaneous determinations of the power transmitted.

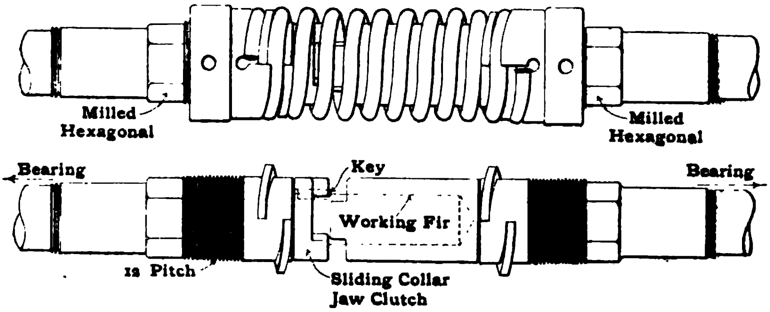


Fig. 3.—Details of Shaft and Spiral Spring Clutch Jaws.

In testing a given motor, the best results have been obtained by using a spring which will give a deflection of 180° when the motor is fully loaded. The brush setting admits of an accuracy within .2 of one degree, and thus the determination of the full load torque can be obtained within one-tenth of one per cent. This compares favorably with the results obtained with the usual laboratory electrical instruments.

The method used in calibrating the dynamometer is illustrated in Fig. 2. It is rapidly and easily effected with the aid of the two long wrenches shown in the cut. These are adjusted on the hexagonal sections of the shaft, one being used as a scale arm and the other as a lever. For any given point the lever is drawn over till the scale arm shows a tendency to raise from its horizontal position; the brushes are then placed on the contact points and adjusted till a clear "click" is obtained in the receiver on making and breaking the battery circuit; and a record is made of the scale arm moment and the deflection scale reading. The calibration curve of the dynamometer fitted with the lightest spring is shown in Fig. 4, and repeated tests before and after use fail to show any change in its calibration constants.

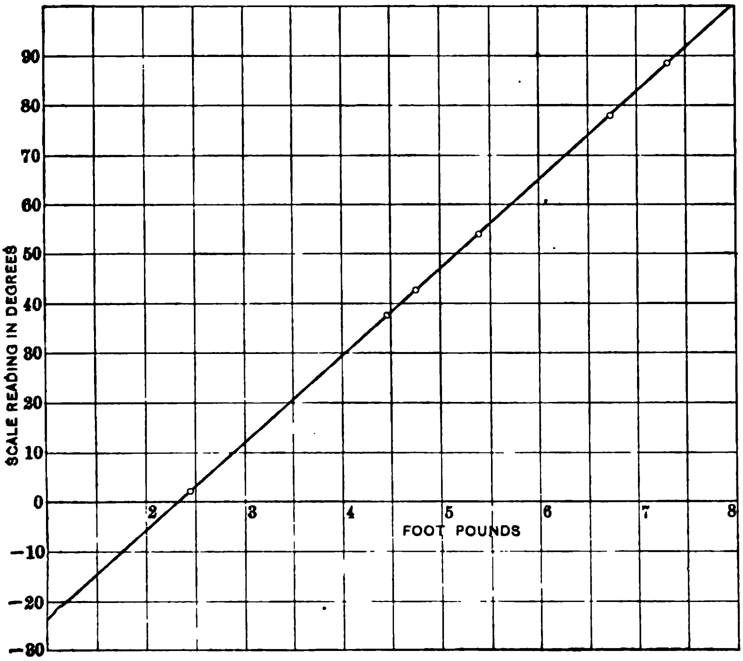


Fig. 4.—Calibration Curve of Dynamometer Spring.

As an evidence of the ease with which accurate results can be obtained, I give here the results of a test made upon a three-phase induction motor conjointly with Mr. Mug, and two seniors in electrical engineering at Purdue University, Messrs. A. F. Chamberlain and C. R. Dooley, to determine the characteristics of the motor. The results may be the more interesting in view of the fact that the test embodied a very simple method for obtaining the mechanical torque developed by the motor at any speed.

The electrical readings were obtained by connecting an ammeter and the current coil of a wattmeter in each circuit, and a voltmeter and the voltage coil of a wattmeter between each terminal of the motor and the neutral point of the three star connected transformers feeding the motor. The voltage was kept constant at 53.7 volts between the motor terminals. The speed was determined by belting a calibrated magneto-generator to the motor shaft and reading the voltage developed at its brush terminals; and the torque from the dynamometer. Every factor entering into the test could, therefore, be obtained simultaneously and very accurately.

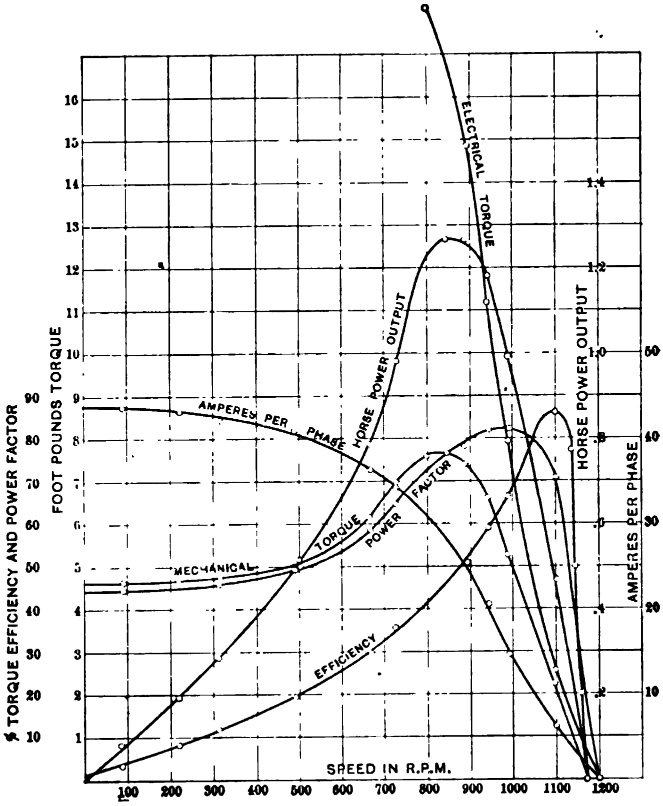


Fig. 5.—Speed Characteristics of Three-phase Induction Motor.

The motor was started up from rest and held at a low speed by the generator. The generator was connected with its two shunt field coils in parallel, instead of in series, across its brushes. With this connection it acted as a short-circuited series direct-current dynamo. To add stability to the adjustment, the series coil of the dynamo was separately excited with a small current. The speed of the motor increased till the counter torque developed by the generator equalled the torque of the induction motor. The speed then assumed a perfectly constant value, and readings were obtained from all the instruments. Next, a resistance was connected in the armature circuit in series with the shunt winding; the induction motor increased its speed until the counter torque of the generator again equalled the torque of the motor; the speed again became perfectly constant, and readings were taken. The speed stability of this arrangement is owing to the fact that the torque of the direct

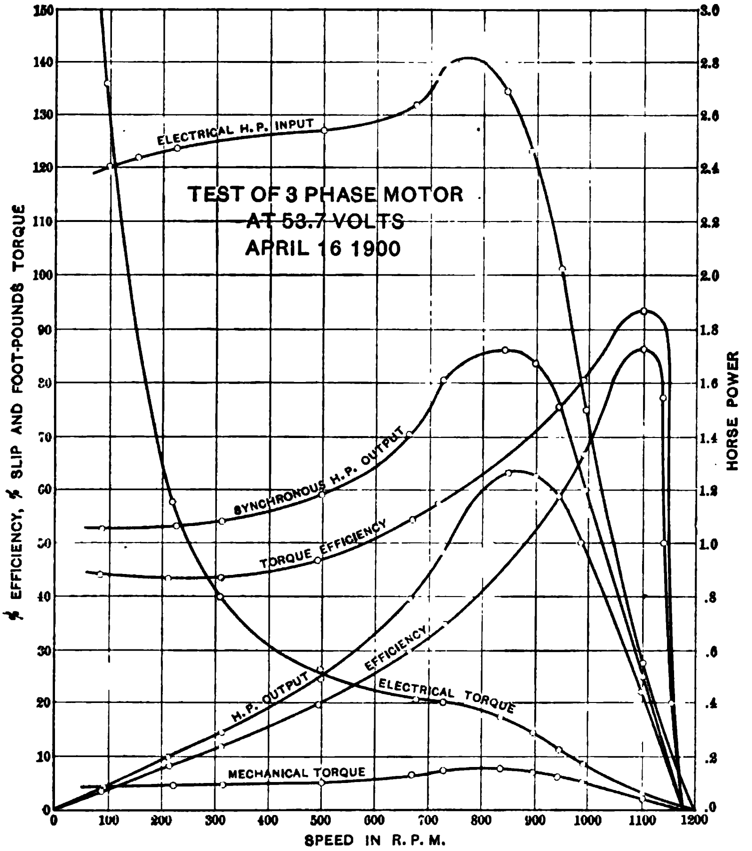


Fig. 6.—Torque Characteristics of Three-phase Induction Motor.

current machine increased very nearly as the square of its armature speed, and therefore very much faster than the torque of the induction motor. Using this adjustment, the speed and torque of an induction motor can be held at all common values at will.

I hope I may be pardoned for dwelling upon these experimental details, but I do not now recall having ever seen a description in print of a simple and successful method of obtaining the torque of an induction motor for speeds below the speed of maximum torque.

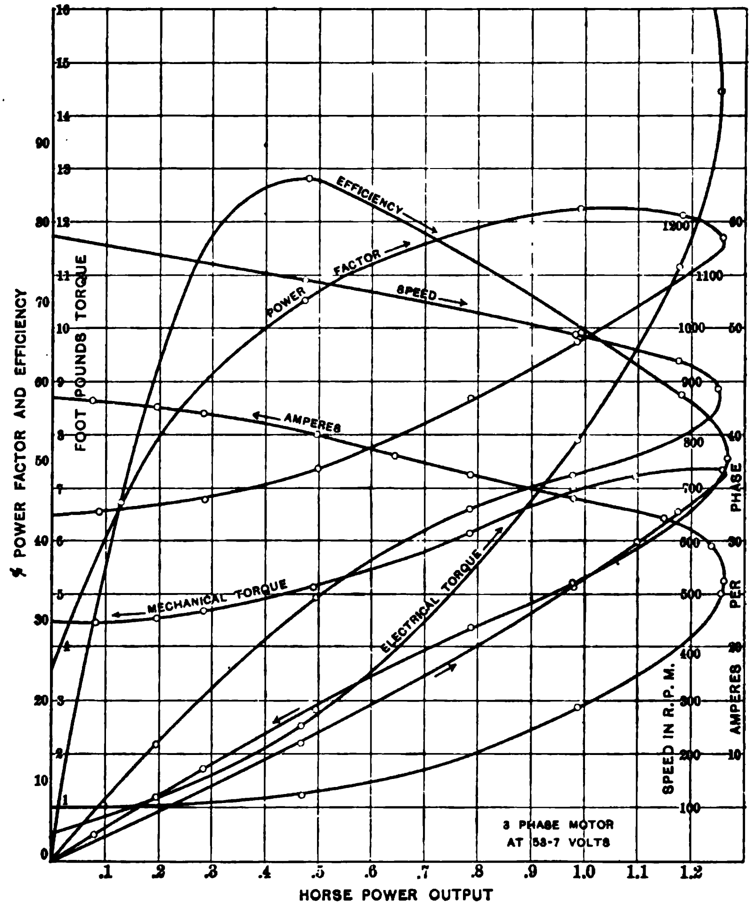


Fig. 7.—Power Characteristics of Three-phase Induction Motor.

The curves of Figs. 5, 6 and 7 show the experimental values of all the characteristics of the motor below as well as above the point of maximum power, and bring out the relations that hold between the several factors at the very low speeds. The curve designated "electrical" torque represents the torque that the machine would develop with the given input if it had an efficiency of one hundred per cent. at all loads.

The curves are chiefly valuable in showing the accuracy with which torque readings can be obtained. The curve of "horse power output" of Fig. 5 depends directly upon the product of the instantaneous speed and dynamometer readings, and is very accurately defined by the plotted points. In tests upon motors of larger capacity the dynamometer is even more satisfactory from the experimenter's standpoint; not because its accuracy is necessarily greater, but because of the more rigid coupling between the machines. There is nothing about the dynamometer to get out of order, the bearing friction is very small and praccally eliminated in the calibrating; the springs are cheap and easily adjusted.

A spring can be taken out and another substituted for it in about five minutes, and the dynamometer can be calibrated in five minutes; but best of all, perhaps, it can be put in the hands of inexperienced experimenters, after having once been adjusted, and be used by them with success, as there is nothing to get out of order.

When the load on the dynamometer is subject to rapid variations, the clutch, shown at the center of the shaft in Fig. 3, should be moved over to the right. It will then lock with the jaw on the right hand section of the shaft in case the deflection exceeds 90° and prevent the possibility of the spring being overstrained.

Lafayette, Ind.,
April 30th, 1900.

DISCUSSION.

THE PRESIDENT:—The difficulty in such transmission dynamometers, has usually been to obtain a stationary indicator of the deflection of a rapidly revolving spring, and this seems to have been overcome in the present arrangement by a very ingenious device. The paper is open for discussion.

MR. C. O. MAILLOUX:—I consider this a very ingenious, effective and practical device. Those who have had experience with transmission dynamometers know that there is very little to be said to commend the very best of them. The most satisfactory ones that I know of are the so-called Emerson type, in which the motion is transmitted through an epicyclical gear train where the torsional moment produces a lifting moment, which is used as the measure of the power transmitted. This machine, which was at one time very largely used, is however open to many objections, not the least of which is friction—the uncertain amount of friction which it has within itself. A later form of transmission dynamometer which is more satisfactory, and with which I personally have had some practical experience, is the VanWinkle dynamometer. It resembles the present dynamometer in the fact that it also measures a moment of torsion, by means of springs. It likewise gives an indication by the relative motion of two disks, which are held together by two coiled springs, the springs being arranged somewhat as in the so-called "Raffard" coupling similar to that which is used on the shaft of the Westinghouse "Kodak" dynamos. Again, however, there are difficulties, one of them being centrifugal action, which tends to throw out the springs bodily, and which causes an error in its reading by introducing additional force, namely, that of centrifugal action in addition to the strain due to the moment of torsion. In the present case the author has apparently avoided this difficulty by placing the spring on the shaft itself where it is no longer subjected to any centrifugal action; and he has also eliminated, so far as one can see, all of the losses and errors due to friction. The only thing which it seems to me the device still lacks is a means of giving a visual indication of the torsional moment; that is to say, one which would read on a scale, or one for reading which you do not have to make adjustments. The instrument in the present form will only give an indication for each particular moment, just the same as when one measures a resistance with a Wheatstone bridge set, where one has to balance for the particular value. In this case the usefulness of the apparatus is somewhat impaired by that fact, because, with fluctuating loads, or with loads which do not remain at a constantly steady value, there must be a tendency to lose the telephone tick; that is to say the torque either exceeds or falls below an amount which corresponds to the position of contact which gives the click on the telephone. Either there must be something like a dash-pot, to make the instrument lest sensitive, and thereby impair its usefulness as an instrument of precision, or else there must be means of quick adjustment, so that, when the torque varies one can still find and follow quickly the clicking spot, which is the thing by means of which the angle of displacement in the two disks is measured. It seems to me that some system of epicyclical gearing could be devised and attached to the outfit that would enable one to get a deflection indication. In the VanWinkle dynamometer a device of this kind is used, which is somewhat complicated, but it is preferable to the present method in so far as it enables one to take a large number of readings in a short time, and this is particularly desirable in the case of fluctuating loads. I should say that where the fluctuations are at all important and large, one would have considerable difficulty in getting satisfactory results with a machine of this kind. You might catch it at some points, but it seems to me that one would not be able to get readily the measure of the fluctuation, for which we must get the extremes, whereby we may get a correct idea of the range of variation; which is something that one often wants to know in making dynamometric tests.

I would like to know whether the author noticed any phenomena in the springs akin to hysteresis. I have sometimes observed that springs do not come back at once to their original form when the tension is released; they seem to experience a kind of hysteresis effect. They eventually get back but it may require considerable time. Of course the nearer the elastic limit is reached the worse that effect would be. Still I think it is noticeable in certain cases even when the strains applied to the spring are much below the elastic limit.

I would also like information regarding the range within which a particular outfit can be used; that is to say, how many springs would one require in a dynamometric outfit which was intended to cover a range of from one to forty or fifty horse power. With the Van Winkle dynamometer it is found necessary to transmit the power at different speeds in order to increase the range. The instrument is not applicable to many cases for which this one is applicable, for that very reason. In this case since we can couple the driving and the driven machines together it seems to me there might be a very wide range of power under great variation of speed.

Prof. Goldsborough :—As Mr. Mailloux's remarks have been directed especially to me, I think I can say, as far as the matter of the dash-pot, for instance, is concerned, that in using the instrument we have found very little difficulty, indeed, from vibration.

I have also used a very successful dynamometer brought out by Professor Flather in which the amount of torque is measured by a series of pistons. These pistons operate in little cups or cylinders which are arranged on the rim of a wheel. For instance, if this represents one of the spokes of the wheel (making diagram on the board) there would be a little cylinder attached here on a pin projecting out in this direction which the piston would fit, and transmit a pressure through suitable connecting means out to a gauge at the end of the shaft. This is a very good form of dynamometer. It is one that can be very successfully used in making tests on all sorts of machine tools, in connection with lathes, etc., where there are rapidly fluctuating loads, and it gives a perfect record where a proper speed counter is used, and where a recording drum is used for recording the torque. It enables one also to determine at any moment the torque which is developed. These instruments are usually of the belted type and have relatively quite a wide range of usefulness.

As far as I know our instrument is most accurate for measuring power and determining torque. The Van Winkle instrument I personally do not like, for the same reason that I object to the Flather dynamometer, in view of the fact that they are somewhat complicated. In getting out our instrument I wanted particularly, if I could, to devise a dynamometer which could be used at all times by the students without any danger of its getting out of order, and without their having to spend most of their time on the dynamometer instead of on the electrical apparatus. In cases where we have used a Prony brake, or other type of dynamometer, we have usually had more trouble with the dynamometer than with all the rest of the apparatus put together. In using the dynamometer which is discussed in the paper there is no trouble at all experienced in handling the instrument. The objection which has been raised, that it is impossible to get a reading of the instantaneous torque developed by the machine without first setting the brushes, is, I think a more or less pertinent criticism I have made drawings for a machine of the same type in which a resistance wire will be used: by having two collector rings arranged and a contact point pressing on the resistance wire, and then having a storage cell acting on a circuit through the wire and a Weston milli-voltmeter the variations in the angle of torque will be determined. In other words, when there is no torque there will be none of the resistance wire in the circuit, and consequently a minimum reading of the voltage by the milli-voltmeter. As the twist takes place in the shaft, the relative position of the two wheels is changed, and more and more resistance is introduced into the circuit. This necessarily cuts down the current and reduces the voltage reading on the milli-voltmeter. This arrangement, I think, can be successfully carried out to give at all times definite readings of torque, when the instrument has once been calibrated. On the other hand it introduces an additional adjustment in the apparatus itself and makes it just so much more complex; just so much more easily put out of order.

We have found it very easy, indeed, to get settings with the two contact brushes. We have found that by putting three Edison-Lelande cells on the circuit and using a condenser of about one microfarad, in parallel with a telephone, the setting can be made very quickly. For instance, in running up the back of the induction motor torque curve, before the method of using the series generator was devised, an attempt was made to use a separately excited shunt-wound machine. A shunt-machine works all right until you get to a certain point on the curve, but after that it is impossible for you to hold the speed of the induction motor constant at any one point. For instance, in the case of the induction machine discussed, the speed-torque curve is, of course, that shown in Fig. 5 (illustrating.) Now the torque curve of the separately excited shunt generator is a straight line for any given resistance in its armature circuit. This arrangement holds the speed at constant values as long as the straight line speed-torque curves of the shunt generator cross the speed-torque curve of the induction motor at an abrupt angle. When, however, the speed-torque curve of the shunt generator becomes nearly parallel to that of the induction motor, owing to the reduction of the resistance in the shunt generator circuit, a condition of instability of speed is reached and both the speed and the torque of the induction motor will continuously rise. However, as the speed rises slowly, we have been able to follow up the torque reading—the man who reads the dynamometer calls off and the men reading the electrical instruments make their records at the same time. In this way we can work quite rapidly and get points right up the back of the speed-torque curve. If there were much difficulty in getting the setting with the dynamometer it would not be possible to follow along the curve. If you wish to have a great deal of stability in the instrument it is not necessary to use a dash-pot; it is only necessary to put in a heavier spring, and by using a stiff spring you can make the adjustment as stable as you wish. Of course, the finer the spring for any given power, the more difficulty you will have in getting your settings, because the angles through which the torsion takes place, as the load is changed, are very much greater.

In regard to the matter of hysteresis in connection with the spring, I have not made any determination whatever. The only determinations that we have made are these. Early in the afternoon, for instance, when an experiment is conducted which includes the use of the dynamometer, it is calibrated. The tests are then performed and immediately afterwards a second calibration is taken. The two dynamometer calibration curves when plotted fall absolutely on top of one another. When we calibrate a voltmeter just before and just after an experiment, or a wattmeter or an ammeter, we frequently find slight differences. The points in the two calibrations may scatter a little, or not fall exactly on one another. In the case of these springs we have found that they fall exactly in line; and so, in view of the fact that the error of the dynamometer must be inside of the error of the electrical instruments, we have not thought it necessary to pay any special attention to hysteresis.

In regard to the number of springs; our instrument has a range up to 25 H. P. and for that range we have five springs, the smallest of which is two-tenths of an inch in diameter and the largest is about seven-tenths of an inch in diameter. With these springs we have a range which covers all machines from two H. P. up to 25 H. P. A very good efficiency curve can be obtained with an angle of only 90° total deflection at full load. You can then go from zero to full load and get very exact readings. If you put lighter springs in, necessarily your results are more accurate because you get a finer adjustment in the scale. I would say, though, for an instrument of this size you need at least five springs. If I were going to build another instrument, for larger powers, I would make it for use between 25 and 100 H. P.

I have found that this dynamometer method can be used by putting two machines in line and simply connecting a spring to the shafts of the machines, thereby removing the necessity of having an extra piece of apparatus. For instance, we have two railway motors in the laboratory; they are lined up and a spring connects the two shafts. The spring in this case acts both as a flexible connection between the machines and also as a dynamometer. A spring costs only about 60 cents, so that the spring is the smallest item of expense.

PROF. A. J. ROWLAND:—There is just one thing that occurred to me in connection with Prof. Goldsborough's paper, a point in design which makes the dynamometer especially commendable. It is not particularly with reference to the dynamometer either, but in connection with the means of recording the results. I refer to the use of a contact-maker. Anybody who has done anything with contact-makers knows how elusive they are; how small, trifling things, that are so subordinate that, though they seem as if they could count for nothing, throw one's results all out. Now in this case we do not look for silence as usual in such devices, but just the reverse. It is easy enough to get a contact-maker to operate so you can hear a tick in the receiver; it is difficult to get a contact-maker to work so that one procures silence. Perhaps it is obvious and so unnecessary to say, but certainly if a contact-maker is to be used, this means of reading, when the click of the telephone is made the guide for settings of the scale, is the only method which could be applied. There is always moving machinery to add to the noise in the receiver. Altogether the instrument as devised must be one which is easy to work with, and a dynamometer by which one ought to get very nice results.

PROF. GOLDSBOROUGH:—As far as the action of the telephone is concerned: in using the machine, my assistant first reported to me that he had no special difficulty in obtaining readings, but thought probably the width of the contact had some effect; so I took some trouble to find out just what the range of accuracy is. In our machine the brush probably has a width of $\frac{1}{32}$ of an inch and a contact point width of $\frac{1}{32}$ of an inch. Now if you have one brush in a fixed position and move the other, you can move it along until you begin to hear a click. Move it a trifle further and the click becomes more pronounced until you get a maximum amount of sound. Proceeding still further the sound will diminish. By taking readings very carefully I have found that in ten readings we could every time bring the pilot brush right back to the same point. If you want to catch just a faint noise, you can get that adjustment. If you want to get the maximum amount of sound you can get that adjustment. Or if you want to carry it too far ahead and bring it back to a faint sounding position you can get that adjustment. So we have found that between zero sound on one side and zero sound on the other side, there is a limit of less than one-half of one degree in the scale reading where the spring is adjusted to give 180° deflection at full load. Half a degree in this case represents a very small error. By careful work, of course, you can make it much smaller. I do not know how the instrument would work if you were using it on very fluctuating loads. I do not know that it would be a success. It was not designed for that. It was designed to use with electrical machinery, where we can maintain our load with absolute constancy, you may say, for almost any length of time; and for that purpose it works nicely. What its value would be in testing lathes or machine tools of various kinds, in which the fluctuations are very rapid, I do not know; but for the use of the electrician and for rapid testing in either commercial or college laboratories, it has so far worked out very nicely, indeed.

MR. MAILLOUX:—I do not quite agree with Prof. Goldsborough as to the limitation of this instrument. I think it is really suited for many more purposes than he thinks, provided it has means of giving an indication of the deflection. I think that is really all it needs. It is free from the series of errors due to speed which are incident to the Van Winkle dynamometer. The only thing that it lacks is a means of giving an indication of those fluctuations, because if there are errors due to resonance, they can be measured, determined and accounted for and allowed for. I think it is possible to apply a device that will give scale indications.

I think really this is a very interesting apparatus, and one which has a far greater range of usefulness than Prof. Goldsborough claims for it.

THE PRESIDENT:—We will proceed with the next paper on "A Percentage Bridge," by Mr. Herschel C. Parker, of Columbia University.

A paper read at the 17th General Meeting of the American Institute of Electrical Engineers, Philadelphia, May 16, 1900, President Hering in the Chair.

A PERCENTAGE BRIDGE.

BY HERSCHEL C. PARKER.

There are many cases in the measurement of resistance that require the exact determination of comparatively small differences. This is true when standard ohms are compared, when a standard rheostat is calibrated by comparing directly with a standard ohm, in the measurement of temperature coefficients, etc.

For the comparison of standard resistances of the same value, the Carey-Foster method, using the "commutator bridge," furnishes a very precise and satisfactory means of measurement.

If, however, a rheostat in which the coils are arranged in sets of 1, 2, 3, 4 or 1, 2, 2, 5 is to be calibrated against a standard ohm, the problem becomes an exceedingly difficult one. In fact two rheostats have to be calibrated at the same time and the corresponding calculations are very involved.

The method known as "substitution in the bridge" (described in "A Systematic Treatise on Electrical Measurements") is perfectly adapted to the adjustment of the coils of a standard rheostat of any pattern whatever by comparison with a standard ohm, but requires the use of interpolation resistances and the observation of galvanometer deflections when a table of corrections is to be made out for a rheostat already adjusted.

The method devised by the writer, which may be called the "percentage method" and the apparatus employed the "percentage bridge," while based on this method, differs from it radically. It is a zero method, makes use of readings on the bridge wire in place of galvanometer deflections, and does away entirely with the use of interpolation resistances.

It seems to possess all the advantages of the Carey-Foster method, while the apparatus required is much simpler using only

4 mercury cups in place of the 20 mercury cups of the complicated commutating device usually made use of. At the same time it gives the great range of measurement of the method of percentage differences.

The arrangement of the apparatus is shown in Fig. 1.

The "percentage coils" C C are joined to the ends of the bridge wire A B and these coils are so adjusted that when resistance in one arm of the bridge is changed by an amount θ the displacement on the bridge wire $= \lambda$.

Let $L = 1$ ohm and $R = 1$ ohm.

Then $(C+A)-\lambda : (C+B)+\lambda :: L : R+\theta$.

Now when $\theta = .01$ ohm, adjust the coils C C so that $\lambda = 100$ divisions of the bridge wire, then 1 division $= .01\%$ (approximately).

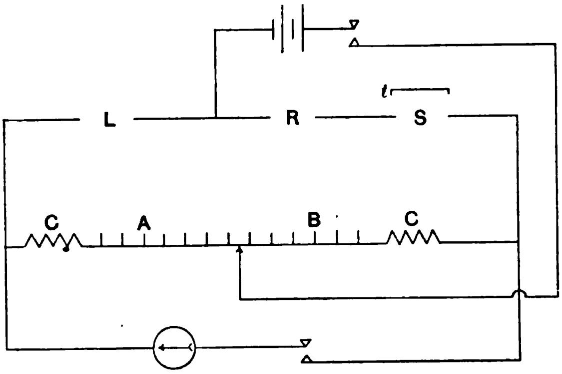


Fig. 1.

If $L = 10$ ohms and $R = 10$ ohms, when $\lambda = 100$ divisions $\theta = 0.1$ ohm (1% of 10 ohms) and 1 division is again .01%.

This being true for any values of L and R, the bridge when once adjusted will always read in percentage.

The value of the "percentage coils" for any given value of the wire AB can be calculated as follows:

Let $A + B = 1$ ohm $= 1000$ scale divisions, and the ratio of the change of resistance $= 100/K$.

Suppose the position of balance to be at the center of the bridge wire, then $A = B$ and

$A + C = B + C = X$. Whence $\frac{X-\lambda}{X+\lambda} = \frac{100}{K}$,

$KX - 100X = K\lambda + 100\lambda$, $X = \frac{\lambda(K+100)}{K-100}$.

If $K = 101$ and $\lambda = 0.1$ ohm (100 divisions),

$X = \frac{0.1\,(101 + 100)}{101 - 100} = 20.1$ and $C = X - A = 20.1 - .5 =$ 19.6 ohms.

To find how nearly this value of C will give the true difference in percentage for any other value of λ we may substitute in the equation $\frac{X - \lambda}{X + \lambda} = \frac{100}{K}$, thus when $\lambda = .001$ ohm (1 division) and K should equal 100.01, $\frac{20.1 - .001}{20.1 + .001} = \frac{100}{K}$, $K =$ 100.00995, which gives an error of only .00005%, and when $\lambda = .01$ ohm (10 divisions), $K = 100.09955$, an error of only .00045%. These errors are, of course, quite beyond the errors of observation:

Thus we may have a bridge that will read in differences of percentage with the greatest accuracy from considerably above 1% to differences in resistance as small as .001%.

By taking different values for λ and K in the equation $X = \frac{\lambda\,(K + 100)}{K - 100}$, and then calculating from the values obtained for X the corresponding values for K from the equation $\frac{X - \lambda}{X + \lambda} = \frac{100}{K}$, it is found that the best ratio of the bridge wire to the "percentage" coils for all usual cases of measurement is 1 : 19.6.

If it is desired to have 1 division of the bridge wire = .001%, then the ratio should be, 1 : 200.5.

If the point of balance is not exactly at the center of the bridge wire the error introduced is very small. Thus, suppose in the case where 1 division = .01% the position of balance was 100 divisions (0.1 ohm) from the center, then when balanced the ratio is, 20.2 : 20.0 : : 1.01 : 1, and when $\lambda = 100$ divisions (0.1 ohm) the ratio is 20.3 : 19.9 : : 1.0201 : 1. Now 1.0201 — 1.0100 = .0101, an error of only .01%.

This error may, of course, be eliminated if necessary by adding compensating wires to either arm of the bridge when the point of balance is a considerable distance from the center.

This form of bridge is of great service in the laboratory when exact and rapid comparisons are desired. An example will best show the method of employment.

Queen Rheostat No. 1 compared with *Standard Ohm* = 1.0005 at 19° C.

Positions on Balance.	Bridge Wire Substitution.	Difference in %.	Correct Value.	No. of Coil.
500	495	— .05	1.0000	1
426	435	+ .09	2.0023	2
409	395	— .14	2.9936	3

This method is especially adapted to the determination of temperature coefficients, for the change from the position of balance divided by the difference in temperature gives at once the coefficient. Since a change in resistance of .001% can easily be detected, the temperature coefficient when a difference of temperature of only 1 degree is employed can be accurately measured. This bridge also gives a convenient means for determining small changes in temperature. If a wire whose temperature coefficient = 0.2% is balanced in one arm of the bridge, then it is possible to measure a change of temperature = .005 degree.

The "percentage bridge" is so easy to construct and adjust, being, in fact, only an ordinary bridge wire with the addition of the "percentage" coils, that it seems possible it may be found useful in many electrical laboratories when the precise comparison of standard ohms or the calibration of standard rheostats is required.

Discussion.

The President:—There already exist many methods of measuring resistances, but there are none too many, as most of us have found frequently, to our sorrow, that often the very resistance we want to measure cannot be measured as well as we would like, by the methods that are known to us. The present method points out the importance of measuring by percentages, and I think that principal ought to be recognized more than it is, because in making such calibrations it is not the absolute values of the errors that we are after, but the percentage value, and a method of finding this directly cannot fail to be of interest. The paper is open for discussion.

Prof. Goldsborough:—I have been very much interested indeed in reading this paper, and in listening to its presentation to-day. I very gladly welcome at all times anything that tends to reduce labor in calibrating instruments of any kind—anything that tends to greater simplicity. The greater the simplicity of the method the greater are the chances of ultimate accuracy in our results. This method commends itself, especially in view of the fact that it is a zero method, and we all know the value of zero methods. A zero method, in which a galvanometer is used may be said to be analogous to a contact method in which we adjust for maximum noise instead of trying to observe a point of silence. It gives us a direct indication that we have reached the desired result. Very frequently it is a very difficult matter to make a galvanometer which is sensitively adjusted, operate satisfactorily, unless we go to a great deal of trouble. At our own University we find that often the street railway currents affect our apparatus, when the street car line is not closer at any point than a quarter of a mile; and I have no doubt that in laboratories in cities which are less favorably located, experimenters experience much difficulty in getting their galvanometers to behave properly. Under these conditions a zero method is all the more valuable, as it eliminates the necessity of taking a reading of a given deflection. We have found instances in the case of very delicate readings that we have been making recently at the Purdue University, that it has been necessary for the experimenters to do all their work between 1 o'clock at night and early morning before the street car lines start up. We reach a time only then when our instruments can be very delicately adjusted.

I very gladly welcome any method which tends to simplicity and greater accuracy with less wear and tear on the human frame; so I think those of us who are in charge of laboratories will welcome this particular device for standardizing our resistance coils as something to be highly commended.

The President:—Is there any further discussion. If not, the Secretary has some announcements to make.

The Secretary:—To-day's session ends with the paper just read. I take pleasure in announcing that the Local Committee has arranged for a "Smoker," which by the courtesy of the Manufacturers' Club will be held at its rooms, No. 1405 Walnut Street.

Mr. Charles A. Bragg, Chairman of the Local Committee then read letters of invitation to the INSTITUTE to visit Cramp's Shipyard, the Baldwin Locomotive Works, and the Franklin Institute.

The meeting then adjourned to Thursday, May 17th.

THURSDAY, MAY 17TH, 1900.

MORNING SESSION.

THE PRESIDENT:—We will now proceed with the other business of the meeting. The first thing on the program is the "Report of the Committee on Units and Standards," by Dr. A. E. Kennelly, chairman.

DR. KENNELLY:—Mr. President and gentlemen, with your permission I will read the report of the committee as addressed to the Council last month.

REPORT OF COMMITTEE ON UNITS AND STANDARDS.

TO THE COUNCIL, AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

GENTLEMEN:—Your Committee on Units and Standards has considered the following resolution passed at the last regular meeting of the INSTITUTE on the 28th of March, 1900:

> *Resolved:* That the Committee on Units and Standards be requested to investigate and report at the ensuing meeting in regard to the advisability of the following:
>
> 1. The giving of names to the Absolute Units of the Electrostatic and Electromagnetic systems.
> 2. The denotation by means of prefixes of multiples of such units.
> 3. The rationalization of the present system, by means of taking the absolute unit of magnetism as equal to the present magnetic line, and the absolute difference of magnetic potential as equal to the present absolute unit of current-turn.
> 4. The advisability of taking up any or all of the above matters at the Congress to be held in Paris this year.

The Committee desires to report as follows:

1. We consider that there is need for names for the absolute C. G. S. units in the Electrostatic and the Electromagnetic systems; also for suitable prefixes to denote decimal multiples and submultiples of these units, in supplement and addition to those already in common use.
2. That the International Electrical Congress convening this year at Paris should be urged to bestow the above mentioned names and create said decimal prefixes.
3. That much advantage would accrue to a universal "rationalization" of electric and magnetic units, and that the Congress be requested to consider the means and advisability of such "rationalization."
4. That we recommend that the whole subject should be brought up as a topic for general discussion at the approaching General Meeting of the INSTITUTE in Philadelphia.

Signed F. B. CROCKER,
W. E. GEYER,
G. A. HAMILTON,
A. E. KENNELLY, Chairman.
W. D. WEAVER.

Dr. Kennelly:—Mr. President, I would ask permission to add a few remarks on these resolutions. I do not know that I am speaking for the committee, although I have no reason to suppose that my remarks are contrary to their views.

We have a very beautiful system of units, which, as we all know, are those of the centimetre-gram-second system. We are taught the great advantage which accrues to the profession from the use of those units, and their great value from a scientific standpoint; and then after we have learned to estimate the beauty and recognize the importance of these units we are told that we must throw them away, for all practical purposes of electrical work, and come down to another system, related thereto in a rather complex fashion, to wit, the volt ampere-ohm system. The volt-ampere-ohm system, is such a system as would be developed if instead of a centimetre of length we employed a thousand million, or a billion of such centimetres, which is practically the distance from the pole to the equator, along the meridian of the earth passing through Paris. The unit of time in that system is the second, the same as in the c. g. s. system; but the unit of mass instead of being the gram is 10^{-11} gram. I don't know how to name that quantity. The unfortunate part of this practical system is that, as we extend it, in order to make both ends meet in our equations, and in order to make it consistent, we have to employ a unit of length equal to the earth quadrant, which is a very unfortunate arrangement, because we do not build dynamos on that scale. The difficulty which confronts us is the anomalous condition of a theoretical system of units which is good but not practically used, and a practical system which is not so good but which is used, while the connection between the two systems is very perplexing and difficult to remember. There was no necessity, as we see it now, to create this present system. We do not need it, excepting so far as custom and practice has made it necessary. There was never any occasion for creating the volt; it would have been quite sufficient if the volt had been the c. g. s. unit itself, one hundred million times smaller and if the prefix had been attached to the word volt which would have signified a multiplication of a hundred million, exactly in the same way as the microfarad signifies a division of a million. That example shows how clearly we could have had a prefix, and all our terminology, all our equations and all our language would have been consistent with the fundamental c. g. s. system on that basis. There are many people who believe that it is unadvisable to create names for the c. g. s. units; they say it would complicate matters too much. Exactly the same reasoning, however seems to apply to animals and flowers, for example. There are hundreds of thousands of genera and species of animals and plants, either existing or that have existed in the past, and all of these that are known with any accuracy are scheduled and have names. Some of them are atrocious names; but it is surely better to call a buttercup a *ranunculus bulbosus* than to call it by some number in a botanical catalogue or system. If we want to talk about units in the fundamental system we have to say so many units C. G. S. Now there is an unfortunate misunderstanding which is likely to attach to any such arrangement, because we have two C. G. S. systems, the electro-static and the electro-magnetic, and unless you say so many units electrostatic C. G. S., or else so many units electromagnetic C. G. S., you immediately invest your statement with some uncertainty; and therefore some name for each fundamental C. G. S. unit is desirable. We have a few names already, such as the dyne and the erg, and these names are of great utility and no one objects to them. We have metre, centimetre and gram, and those names do not give us any great disadvantage or trouble. Surely it would be no disadvantage to have additional names, even if we never used them; if they were laid on the shelf, the worst that would happen would be that they might be laid permanently on the shelf. The next point, about prefixes for multiples, is surely very important and self evident. We have at present the deka, hekto, kilo, myria and mega, only five prefixes to determine decimal multiples in the ascending scale. It reminds one very much of those savages in Africa who can only count one, two, three, four, five; and we smile at the simplicity of a language which is so imperfect that they are not able to express numerals further than that. Our own civilized nomenclature in electromagnetics is similarly defective considering that in our fundamental physical, electrical and magnetic system we have no multiple of units beyond five in the ascending scale and four in the descending scale. Prefixes for the multiples could be created whether we used them or not. They should be created and they should be consistent. If they are created properly, even at this time, thirty years after the original introduction of the system, we can so take up the practical system with the fundamental C. G. S. system as to give no inconvenience. We could then use the C. G. S. system in practical work, in spite of the fact that the other system is in universal use. The worst that could happen would be that the names would sink into innocuous desuetude. No harm would be done and much advantage might arise.

In regard to the question of the rationalization of units, we now know that the B. A. system might have been better constructed if the fundamental entities had been fluxes instead of point poles and point charges. In order to rationalize the units upon the proper scientific basis, and rectify the existing system. it would be necessary to change all our ohms, volts, amperes,—every electric unit that the electrician employs to-day. It would avoid endless trouble in contracts and endless trouble in machinery and labor. It is a most serious question. It is a question of the rationalization of units after they have been established, adopted by the governments, and after they have been brought to universal use in the last thirty years. A suggestion, has, however, been made as a sort of half means of eradicating this trouble, a suggestion due to Professor Fessenden, I believe, and also to others; that is by employing the permeability of air circuits, the unit of which shall be four π instead of one; in other words giving to air a permeability equal to four π that we would be able to cancel out the four π in our equations; the μ would then be cancelled out the four π. That is a possibility that has been favorably discussed, although there are some who think it would be a disadvantage. The question is entirely separate from the question of giving names to the C. G. S. units. The two things must be considered each upon its own basis, and one proposition does not in any way interfere with the other. The committee has therefore agreed that this question of rationalization could be considered with advantage as to whether it is advisable. But we do not think there is any question as to the advisability of giving names to things which already exist.

THE PRESIDENT:—Gentlemen, this report is now before you for discussion. In view of the Congress in Paris this year this subject ought to be very fully ventilated and discussed at this meeting. The report, as you have seen, is very conservative and does not suggest any very radical changes. The question of naming the C. G. S. units is, as was very well shown by Dr. Kennelly, something which at least will do no harm and it may do much good; it therefore seems that there could hardly be any real objection raised against it. In order, however, to properly bring it before the Congress, it seems to me we ought to go prepared to suggest certain names and prefixes. At the Congress of 1891, in Frankfort, Germany, to which this INSTITUTE sent a delegation, of which I was a member, we tried to have certain things adopted, among other things the henry and the gauss, but we saw very soon that it was hopeless to try to introduce anything new at such a Congress. A Congress is an occasion to settle upon something which has been discussed thoroughly before the Congress meets; it is hardly the place to bring out something new, to discuss it, and then to decide on it. It would therefore be very desirable if we could formulate our recommendations to the Congress and have them published at once, so as to give the Europeans a chance to look them over and consider them. If we wait until the Congress meets and then bring up these matters, it will no doubt result in failure to adopt our suggestions.

There have always been objections to introducing any new system of units; but nevertheless it seems to me that it would be well to have an entirely new system, perhaps something like the one proposed by Heaviside, which would be of great benefit to scientists and to physicists, even though it might be quite different from the one used in practice. In my opinion there would be no objection to adopting a perfectly rational system of physical units in order to enable physicists and scientists to work with it; when they wish to connect their results with those stated in practical units they can do so very readily. If such a system of physical units turns out to be much better than the present c. g. s. system, it will find its way into practice in the course of time; perhaps not during our lives, but later; its foundation would be laid. Therefore I think that the more rational and the more thorough such a new system of physical units is, the better. If we are going to adopt anything new let it be something which will require no further changes later on.

As to the system of practical units, it seems to me that it is not necessary to have any specific practical units at all. In other systems of measurement that we deal with, such as those of weight, length, and so on, we have no practical units. We use the meter when that is the most convenient; we sometimes use the centimetre or the inch or the mil or the mile. It is not necessary to decide that any one of these lengths should be called the unit; we use whatever unit happens to be the most convenient. If we had a system of c. g. s. units with names, there is no need of saying that just so many c. g. s. units shall be determined upon as a practical unit, and be called by another name.

The report is open for discussion.

Mr. C. O. Mailloux:—I wish to call attention to one instance in which a unit has been named and has afterward fallen into innocuous desuetude, to use the language of Dr. Kennelly. Before the Congress of 1881, at which time the ampere, the practical unit of current, had not yet been named, there was a tendency, especially among the Germans, to use the word weber for that purpose; and at the Paris Congress of 1881 there was a certain amount of contention between the advocates of the word weber, and those of the word ampere, as the practical unit of current flux. The strife was quite sharp and I believe it was finally settled by giving the name ampere to the practical current unit, and giving the name weber to the c. g. s. unit; so that to-day we have, at least theoretically, the name weber to express a unit equal to ten amperes. In other words, to put it differently, our ampere is really a deciweber, as it stands to-day. It seems that this application of the word weber became forgotten, from sheer want of use, and it lay on the shelf. We never found use for a unit term of ten amperes and consequently we never had occasion to use the word weber. Later on, I think this Institute proposed to use the same word as a unit of magnetic flux; and if this suggestion should be adopted we would really find ourselves with the same name for two different units, one the absolute current flux value, and the other absolute magnetic flux value. This shows the importance of having a system in the formation of names. If at the time when the weber was christened, names had also been given to the other c. g. s. units, it is not likely that this word would have been forgotten; but it was the only C. G. S. unit that received a name, and for that reason it became forgotten.

I myself think that the naming of the C. G. S. units is desirable, and I think that when we have these names, with a system of prefixes expressing multiples and submultiples, or else powers of ten, we will have all that is necessary for practical purposes. In different industries we use the centimetre as the unit. In watch-making, for instance, the centimetre is the fundamental unit. What corresponds to the foot of the carpenter is the centimetre of the watch-maker. The chemist uses the centimetre as the unit of length and uses the milligram as the unit of weight. In practical work we use the kilogram as a unit of weight. They are all based on the same thing, and the prefix milli, or kilo, added to the word gram, really makes the practical name and there is no need of a specific name in these cases. It seems to me that after all, the logical system is one that is self-explanatory. There is no objection to microfarad, because we know what it means; and it seems to me that when we have named the other units all we shall need will be a rational system of prefixes designating the multiples or subdivisions in the ascending and descending scales, respectively.

PROF. GOLDSBOROUGH:—I have been very much interested in these matters, the naming of the electromagnetic units and the rationalization of the system. I am heartily in favor of appropriate names being given to the electro-magnetic units, but at the same time some care should be used in extending them and in arranging for prefixes and suffixes. At the present time we use the words milliampere, millivolt and kilogauss, and various other prefixes which indicate submultiples or multiples of units which we call our practical units, and they have to us a real value and they carry with them a real significance which it would probably take much time to efface and in their stead use prefixes or suffixes in conjunction with the C. G. S. units. Of course, as far as the word gauss is concerned, it has never been adopted by any International Congress. It is a word, however, which the INSTITUTE has sanctioned, I believe, in the same way that it has sanctioned the terms gilbert and weber. I do not know how generally they are used among engineers; but certainly to those who make use of them they become very valuable, and to my mind if any international names are given they should be in line with the suggestions of the INSTITUTE, if possible.

As regards the rationalization of the system of C. G. S. units, there seems to me to be very little in the way of carrying out the suggestions that have been brought forward and discussed, largely emanating from Prof. Fessenden. To my mind the electricians of the world will have no great difficulty in changing their mental attitude so as to prevent ambiguity of thought. In connection with the work of education, I think the future generations will owe us a debt of gratitude for making this change, as it will make their concepts of the system of units with which we have to deal more clear. There may be some slight advantage in having the permeability of air unit but it is not a very pertinent one. I think when the idea is first presented to the student and he is told that the permeability of air is 4π, that will settle the matter for him, and there will be no further question or ambiguity in regard to it. The older students will have some difficulty in readjusting their mental concept as regards the permeability of air. This, however, is a small matter in comparison with the great good that will result from these changes.

I think the committee acted very wisely in giving to us a conservative phraseology in their report. If we go before the International Congress with suggestions which affect all engineers, of all countries, we will have necessarily to be very careful about the recommendation of terms. It might be a good plan for our delegation to have in mind recommendations for naming these units, which the American engineers can back and heartily support. I presume in whatever names are given there will have to be a distribution of them among the various elements that are represented along the lines of nationality. However that may be, the work of the committee deserves our high commendation, and I hope a motion will be carried at this meeting which will give official sanction to the report which the committee has presented to us to-day.

PROF. W. S. FRANKLIN:—I have been very much interested in this matter of the improvement of our systems of electric units which has been discussed so much for the last two or three months, and I am in full accord with the report of the committee. There is just one thing that I would like to say in regard to the rationalization of units, and that is this: To most minds the eruption of 4π seems to be the only irrational thing in connection with our electrical units; but it seems to me that the most irrational thing is the fact that we have two systems. The fact is, I think, we are not ready to rationalize our units; I think it is an impossibility, because we do not know enough about the subject; so I think the committee has taken a very wise stand in not recommending the INSTITUTE to take a definite stand on that subject. On the other hand, I think it would be an immense advantage to adopt a simple series of names and prefixes for C. G. S. units and multiple units. For my part, I think that a teacher is more able to judge of the difficulties which are involved in our systems of units than practical men, because he has occasion every year, to go through, in a sort of way, the same experience that an engineer has to go through only once in his lifetime; that is, he observes others go through the formative period when they are becoming familiar with the theory of electricity. I think the greatest difficulty that I encounter in teaching the subject of electricity is due to the fact that the C. G. S. units have no names. The practical units are the *practical units* because they have names. I heartily endorse the committee's action and I think the INSTITUTE ought to take steps to formulate its views on the subject for presentation to the Paris Congress.

MR. C. P. STEINMETZ:—I fully appreciate the fact that the absolute C. G. S. units, with the proper system of prefixes, would cover all the needs of electrical engineers and would be far preferable to the present system of C. G. S. units. But I do not think it proper at this late day to change over. The practical units, although inferior to the absolute system of units, have been introduced to such an extent that there is little probability they will ever be replaced. The name "weber" and one or two other names are rarely met. In replacing the present names of E. M. F., etc., I think we would find very great difficulty.

Coming to the system of prefixes, this is undoubtedly a very desirable proposition, as seen by experience, which has already introduced such prefixes as milli, mega, etc., but I should be strongly opposed to any attempt to introduce too many prefixes. When the metric system was introduced on the Continent, an attempt was made to introduce prefixes for every one-tenth in the ascending and descending scale. Practically all these prefixes have been discontinued, with the exception of kilo and milli, except in very few instances.

It appears to me that prefixes in the ascending and descending scale, following each other by thousands, would be sufficient, as milli and micro in the descending, and kilo and mega in the ascending scale.

With regard to the rationalization of our units, I do not agree with our committee. I think any attempt to rationalize our system of units would cause such a confusion as to be very undesirable, and I do not think that matters would be bettered thereby, since even such a rational system of C. G. S. units is not rational at all, as can easily be seen if you try to derive some unit from centimetre, gramme and second, in several different ways. If the system is rational you should get the same dimension no matter how you derive the unit. But in reality, starting from the action of magnetic masses upon each other, you get entirely different dimensions, as starting from the action of electric quantities upon each other. The reason is that neither of the two systems, the electromagnetic or the electrostatic, are rational, but in the former the assumption is made that the permeability of space is unity, in the latter the assumption that the dielectric constant of space is unity, and neither is obviously warranted. But there is another system of units, that is the mechanical system, where you would start by the gravitational attraction of unit masses upon each other in unit distance. Now it may be possible to bring the different systems into agreement by assuming for the dielectric constant of space and the permeability of space such values as to make the action of magnetic and electric quantities upon each other to agree with the action of masses upon each other by gravitation, but such a change would be so far reaching that I do not think it could be introduced at this late day.

Mr. Mailloux:—I wish to call attention to a suggestion which might be of interest in connection with the matter of prefixes. I know an eminent analytical chemist who uses frequently the terms centi and milli, repeating them to designate a submultiple. For instance, in analytical chemistry the word milligram is used to indicate the unit of mass, but my friend uses the terms decimilligram, centimilligram and millimilligram, and thus brings the value down to as low as the ten minus sixth power. So this represents a step in the right direction so far as the descending scale goes. It is possible that a similar expedient might be adopted for repeating the prefix terms in the ascending powers, and likewise bringing us up to the eighth or tenth exponent.

I think Mr. Steinmetz is in error when he says the term deci is not used. It is used very largely by French writers and also by German writers. The expressions decilitre and decimetre are both used largely, in both these countries and, of course decimetre and millimetre are used very extensively all over the world.

Prof. A. J. Rowland:—There are one or two trifling things that have occurred to me. I don't know that they will contribute very much value to the discussion. It seems to me the whole question of the desirability of more units hinges very much on whether you look at this thing from the standpoint of pure science, or the standpoint of engineering. I can see a great deal of use in giving special names to the c. g. s. units if these units are to be used by people who are interested in pure science, but I am not so sure that they would have so much value to engineers. We have two systems now which engineers have to know and handle, the foot-pound-minute system and the centimetre-gram-second-system.

The advantages of the c. g. s. system are obvious to anyone who has used it at all, and yet in spite of its universal use by scientists the world over, and in spite of the legislation which has officially adopted it in this country, engineers scarcely use it at all in their work. Hence before engineers will use more c. g. s. units, they must come to use those we have already.

Some people have called attention to a possible confusion in the names given to c. g. s. fundamental units and c. g. s. practical units. There are difficulties in the use of units now at hand which are quite as bad. Take the magnetic units, for instance; take a unit which expresses the intensity of magnetic flux. One can speak of the intensity per square centimetre or square inch. When intensity of magnetic flux is mentioned I often find great uncertainty as to what is meant. When somebody comes to talk to me about intensity of magnetic flux and uses a number which is near to 100,000, I of course recognize that that is another way of thinking about it than mine; that it is the intensity per square inch; but somehow my mind fails to get that particular grasp on the numerical quantity which attaches when the thing is in square centimetres.

Recently there has been a great deal of concession in the matter of units to the practical electricians. I don't know that it is particularly to be welcomed but the fact remains. Here is the matter of electromotive force, or difference of potential. Those terms are very rarely used among practical electricians, but quite often we hear the term "voltage"; and (much worse) how often do we hear the term "pressure." I don't know what a student of pure science or even an engineer can think of that. It seems to me that it is a great pity that in such matters there has to be a concession made. But in the matter of units, if we multiply units, it seems to me the practical electrician is the man who is going to hold to the old units to the very last possible extreme, and since concessions have already been made to him, concessions will doubtless have to be made in the future. The result will be that if there are units in the C. G. S. system and the pure scientist uses them, the engineer, in contact with practical electricians on one side and pure scientists on the other side is going to have a very hard time of it.

Mr. Steinmetz:—To illustrate what the last speaker said, I may give some of my experience. About eight years ago in the company with which I am connected, we used C. G. S. units for magnetic flux, etc., that is the metric system for the calculation of machines. At the present time we use lines of magnetic force per square inch, etc, because experience has shown that while for scientific reasons the C. G. S. units are the only correct ones, they are very inconvenient in practical design since all the dimensions ultimately have to be given in inches and a calculation in centimetres thus means constant transfer from one system to the other system, and the time is too short to do any work which is not necessary. It appears to me, therefore, that as long as the metric system is not used throughout the country, in machine shop practice, etc., the use of the metric system in design and calculation for practical application will remain limited.

The President:—If there is no more discussion a motion will be in order concerning the disposition of this report.

Prof. Goldsborough:—I move, Mr. President, that the report of the Committee be accepted and adopted by the Institute, and transmitted to the delegates, for presentation before the International Congress. Seconded and carried.

The Chairman (Prof. Owens):—The next thing on the program is a paper by Mr. Fitzhugh Townsend of Columbia University, on "The Relation Between Hysteresis and Eddy Current-Transformers." The paper will bring out a rather peculiar matter which he has noticed and will no doubt be of considerable interest.

A paper presented at the 17th General Meeting of the American Institute of Electrical Engineers, Philadelphia, May 17, 1900. Vice-President Owens in the Chair.

EDDY CURRENT LOSSES IN TRANSFORMERS.

BY FITZHUGH TOWNSEND.

Experiments dealing with the peculiar phenomena connected with the magnetization of iron have been in progress at Columbia University for a number of years.

In the spring of 1899, a further attempt was made to study the components of the exciting current of a transformer, and their relation to the fundamental component, together with the laws governing the phase displacement and amplitude of the latter. This investigation is still going on, and on completion, the results will be published by Dr. Pupin in conjunction with the author of the present paper.

The experiments described in these pages are an offshoot of the main research just alluded to. Their object is to show that the eddy current loss in a transformer appears to fulfil the relation

$$W_e = K B^{1.6} f^2 \text{ and not}$$

$$W_e = K B^2 f^2$$

as is generally assumed to be the case.

It was found in 1899 that the phase of the exciting current of a transformer was practically independent of the frequency, and varied with the flux density.

A coil wound upon an iron core does not behave like an ordinary induction. The current has a certain hysteretic angle of lag which depends only on the magnetic induction. This angle of lag is probably due to some magnetic property of iron which is not as yet understood. It is not due to a true inductance.

According to the experiments to be described, the equation

$$W = B^{1.6}(K_1 f + K_2 f^2)$$

represents the hysteresis and eddy current losses in a transformer.

$$K_1 B^{1.6} f = W_h = \text{hysteresis loss},$$

$$K_2 B^{1.6} f^2 = W_e = \text{eddy current loss}.$$

The modification of the generally accepted expression for the core losses of a transformer involved in this equation, lies in the fact that the eddy current losses are proportional, not to the square, but to the 1.6th power of the magnetic induction.

If, as appears to be the case, the eddy current losses do vary in this manner, it is a fact so peculiar, and so opposed to preconceived ideas on the subject, that some attempt at explanation is necessary.

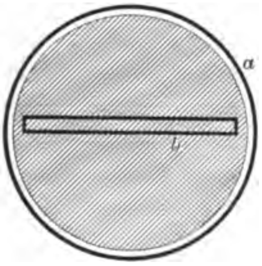


FIG. 1.

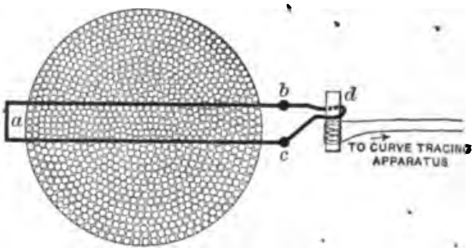


FIG. 2.

In order to arrive at an explanation, the most promising method of procedure will be to consider carefully the conditions under which eddy currents occur.

Fig. 1 represents a section of the core of a transformer. *a* is a short-circuited turn wound around the core. *b* is likewise a short-circuited turn, the only difference being that it is embedded in the iron. If the core is laminated horizontally, *b* will represent substantially the path followed by the eddy currents in a single sheet of the laminations.

The iron core is supposed to be uniformly wound, so as to form a perfect solenoid. Let the ohmic resistance of this winding be so small as to be negligible. A simple harmonic electromotive force is impressed on the magnetizing turns. Let us assume that there are no eddy currents throughout the mass of the iron, and that the induction is uniform. It will also be of necessity a simple harmonic function, that being the form of the impressed electromotive force.

Owing to the varying permeability of the iron, however, the magnetomotive force H will be a complex harmonic.

The turn *b* embedded in the iron encloses so few lines of force that the coefficient of mutual induction between *b* and the magnetizing turns is very small. On the other hand, all the lines of induction which pass through *b* are likewise interlinked with the magnetizing turns.

If now a simple harmonic electromotive force is impressed upon the primary circuit, the secondary *b* will have induced in it a similar electromotive force. This secondary E. M. F. will be 180° behind the primary E.M.F.

The resulting secondary current C_b will produce no appreciable effect on the primary current, either in respect to phase or amplitude. The reason for this is that the electromotive force of mutual inductance in the primary circuit due to the current in the coil *b*, namely C_b, is negligible.

C_b, however, has an effect on the magnetic distribution. It is a counter magnetomotive force, and it must combine with the primary magnetomotive force H to produce a simple harmonic flux.

The current C^b, therefore, is a magnetomotive force acting in such a way as to give rise to a simple harmonic flux in the iron. It is, therefore, to be expected that it should possess, in common with the primary current, those peculiar characteristics with regard to wave shape and phase displacement which characterize every magnetomotive force producing a simple harmonic flux in iron.

The current C_b should lag behind the secondary electromotive force to the same extent that the primary current lags behind the primary electromotive force. This angle of lag depending only on the magnetic induction and not on the frequency, as already stated. C_b should also be a complex harmonic current wave, similar in shape and following the same laws as those which govern the primary current.

When the flux density varies, the electromotive force acting on *b* increases in direct proportionality as in the case of the primary circuit; the frequency remaining constant. Now, if the current C_b follows the same laws with regard to phase displacement and wave-shape, as those which govern the primary magnetomotive force H, then the energy in *b* must vary as the 1.6th power of the induction as is the case in the primary of the transformer described in connection with Fig. 1.

If the frequency varies while the induction remains constant, then, under the supposition of similarity between C_b and the magneto-motive force H, the phase displacement of C_b should remain constant. Therefore, since the voltage and current in the circuit *b* are each directly proportional to the frequency, the watts in *b* must vary as the square of the frequency.

In order to pass from Fig. 1 to the case of an actual transformer, we have only to perform an integration by considering the effect of a large number of circuits similar to *b* lying in planes parallel to each other. The integral energy loss, representing as it does, the eddy current loss in a real transformer, may be expressed by the equation.

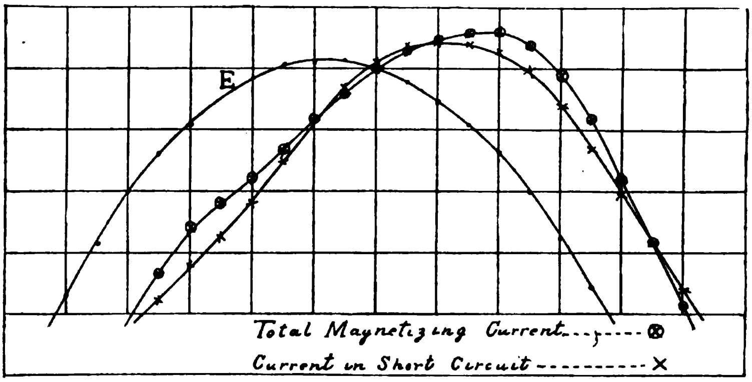


FIG. 3.

$$W_e = K B^{1.6} f^2.$$

It is interesting to compare the conditions which exist in a circuit such as *a* in Fig. 1, with those just discussed as characteristic of the circuit *b*.

a as has been already explained, consists in a turn of wire forming a short-circuit around the core.

The mutual inductance between *a* and the primary turns is not negligible. Also, *a* will have considerable inductance, since a current flowing in *a* will produce a leakage field, the lines of force of which will not cut the primary turns.

A current in *a* can only affect the magnetic distribution in so far as it blows out some of the lines of force. The path of these lines is mainly through air and not through iron, hence the magneto-motive force, to which they are due, should not be expected to be a complex-harmonic wave. The current in *a* should, however, lag behind its electromotive force, owing to the inductance of the circuit *a*.

In order to discover if there is any foundation for the above speculations, a core made of iron wire was procured, and some magnetizing turns wound uniformly around it. Two brass plates were stuck through the body of the core and soldered together at *a* as shown in Fig. 2. The two other ends *b* and *c* were connected together by a short and heavy copper cable. One turn of this cable was put around the small open circuit transformer *d*, and the curve of the current in the short-circuited turn *a b c* obtained[1].

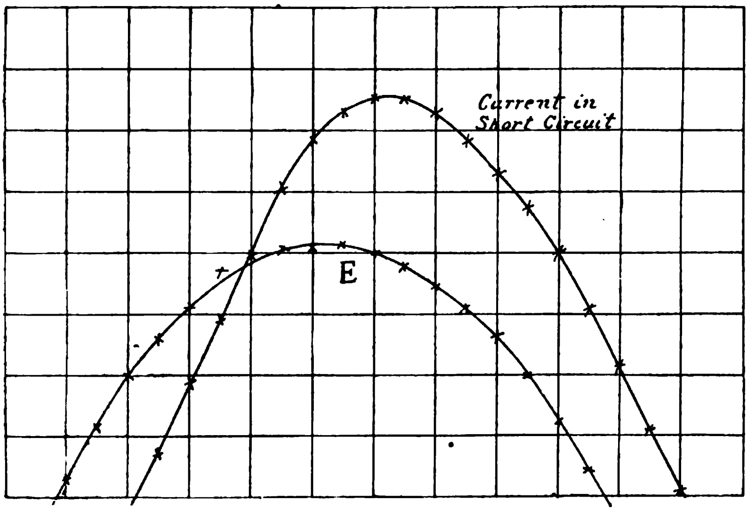


FIG. 4.

The circuit *a b c* is a fair imitation of the elementary current *b* of Fig. 1. The magnetization of the transformer *d* is so small as not to interfere materially with the results.

Fig. 3 shows curves of impressed primary electromotive force and primary current, in addition to the curve of current in the short circuit *a*, *b*, *c*. It will be seen that this latter appears as a lagging complex harmonic wave, as suggested above.

---

[1] The method by which the curve could thus be determined is described on Page 5.

Fig. 4 shows two curves. The one marked E is the impressed electromotive force curve. The other is the curve of the current in a short-circuited turn of wire entirely encircling the core. This curve is a practical example of the current in coil *a* as discussed in connection with Fig. 1. It is very nearly a simple harmonic, and lags behind the impressed electromotive force.

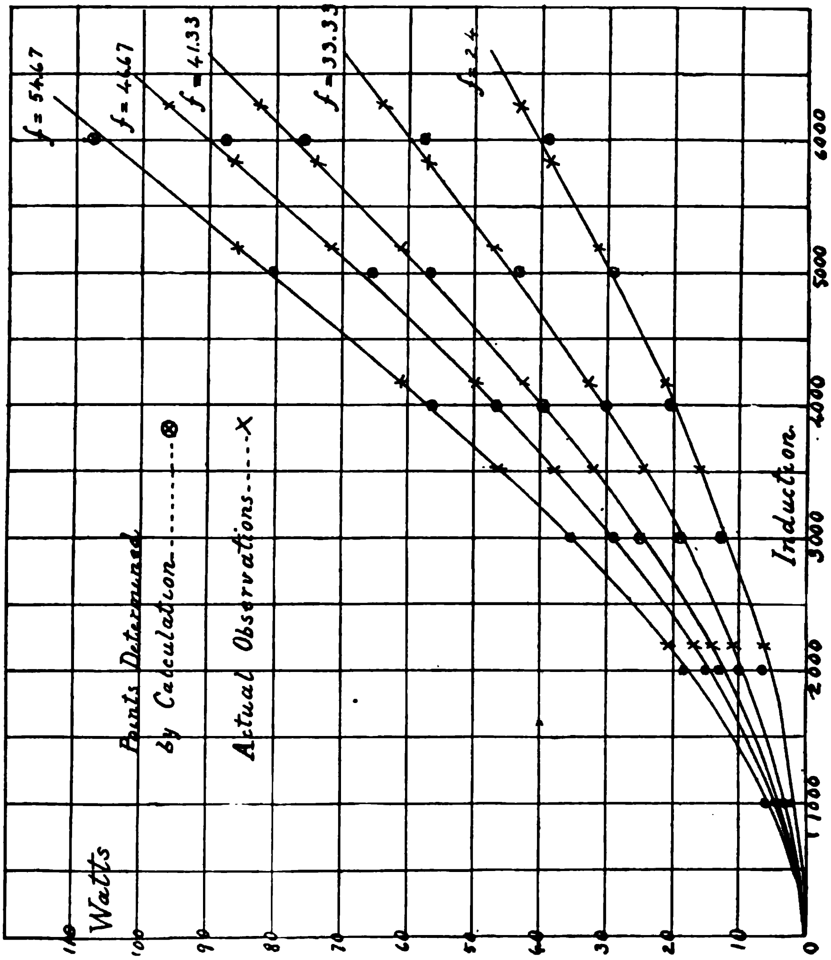


FIG. 5.

An important corollary follows from the expression

$$W = B^{1.6}(K_1 f + K_2 f^2)$$

if this equation is indeed the correct one. This corollary is that the ratio of hysteresis to eddy current losses is independent of the magnetization. Let Wh and We represent these losses, then

$$\frac{W_h}{W_e} = \frac{K_1}{K_2 f}$$

Also, the relation between $\frac{W_h}{W_e}$ and f is an equilateral hyperbole. This relation is what might

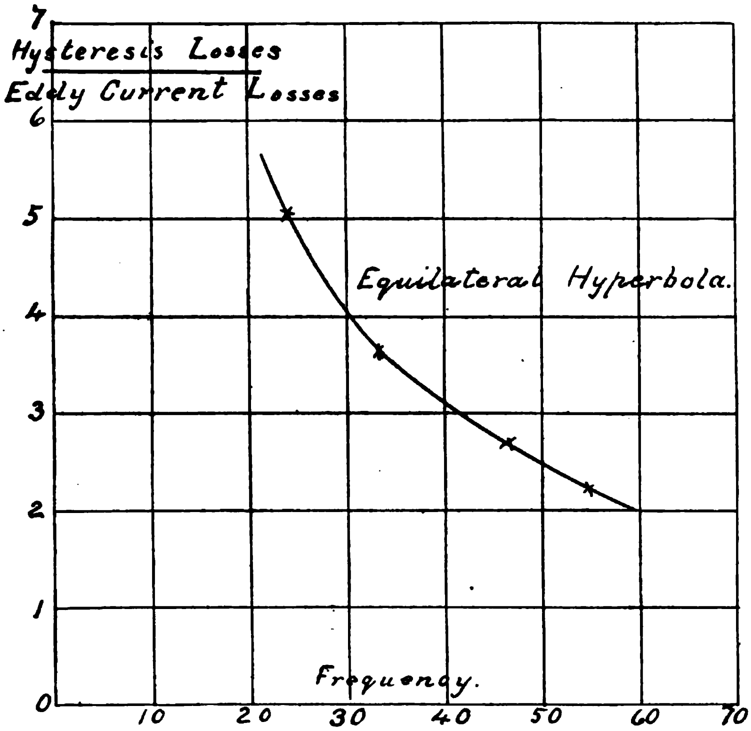


FIG. 6.

be expected, as there is no doubt that

$$\frac{W_h}{W_e} = \infty \text{ when } f = 0,$$

and probably

$$\frac{W_h}{W_e} = 0$$

at very high frequencies.

Prof. W. Peukert, in the *Elektrotechnische Zeitschrift* of

September 21st, 1899, published an article on the iron losses of a transformer, in which a large number of measurements of core losses at different frequencies and magnetizations are tabulated.

The transformer used in his experiments was a closed circuit laminated iron ring built of sheets 19.7 mils in thickness.

These results were plotted as shown in Fig. 5. By taking a number of simultaneous values, the average value of the constants

$$K_1 = 1.223 \times 10^{-6}$$
$$K_2 = 1.006 \times 10^{-8}$$

were determined.

The points shown ⊕ ⊕ ⊕ in Fig. 5 were obtained by substituting the above values of K_1 and K_2 in the equation

$$W = B^{1.6}(K_1 f + K_2 f^2)$$

The agreement between the observed and calculated points is probably as close as is warranted by the accuracy of the experimental determinations.

Table I gives the experimental data from which the curves of Fig. 5 were derived.

TABLE I.

Frequency.	B max.	2187	3582	4173	5192	5843	6260
24	Watts	6.2	15.9	21.3	31.4	38.5	43.2
33.33	Watts	10.9	24.7	32.9	47.0	57.1	64.0
41.33	Watts	14.1	32.2	42.7	61.2	74.0	82.6
46.67	Watts	16.8	37.8	49.8	71.4	86.2	96.3
54.67	Watts	20.8	46.3	60.9	85.7		

TABLE II.

Frequency.	αB	30	39.3	48.2	58.5	66.5	74.5
49.7	Watts	26.3	40.5	54.6	74	91	112
70.2	Watts	35	58	79	101.	127	152
90.7	Watts	50	76	105	136	171	208
121.7	Watts	70	105	144	192	235	284
134.3	Watts	76	114	161	213	263	314

Fig. 6 shows the equilateral hyperbola relating $\left(\frac{W_h}{W_e}\right)$ and f, for the data given by Prof. Peukert.

The experiments just mentioned were made, it must be remembered, on a transformer with closed magnetic circuit. It seemed desirable, therefore, to obtain similar data from a commercial transformer.

The results in Table II were obtained from a five kilowatt Stanley transformer. Inasmuch as neither the cross-section of the iron nor the number of turns were known, it was not possible to determine the magnetic induction. The core loss in watts was therefore measured at different frequencies, for six different

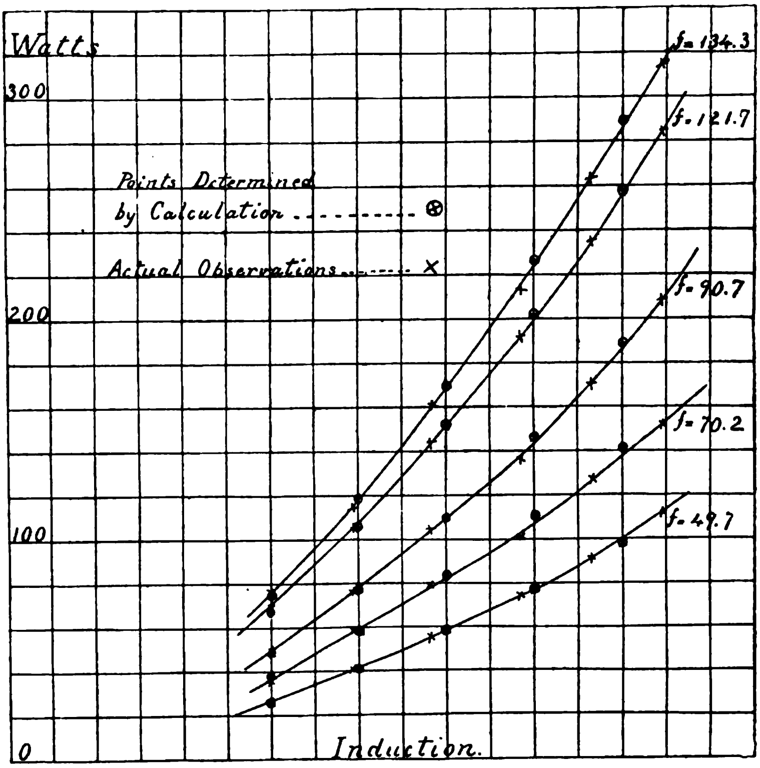


FIG. 7.

field strengths of the alternator used to excite the transformer. The numbers in the column headed *ab* are therefore not flux densities, but the voltages at the different field strengths at the frequency of 121.7. These voltages are proportional to the magnetic induction in the transformer at the different field strengths of the alternator, since the magnetic induction is proportional to the ratio of the voltage to the frequency. At any other frequency, for the same field strengths of the alternator, the corresponding values of the induction will be necessarily unchanged, since the ratios of the impressed voltages to the frequency are the same as at the former frequency for each and every field strength.

The data of Table II is plotted in Fig. 7. The formula for the core losses was then applied in the same manner as in the case of Fig. 5. The agreement between the calculated values and those determined by experiment is again quite satisfactory. Fig. 8 shows the equilateral hyperbola, giving the relation between $\left(\frac{W_h}{W_e}\right)$ and f.

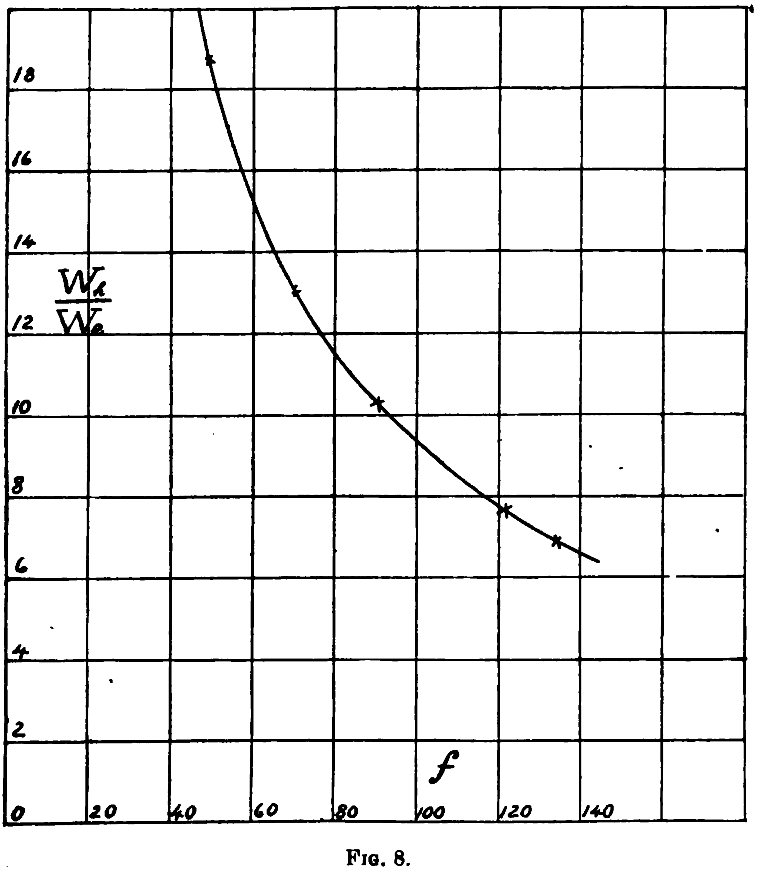


Fig. 8.

The close agreement between theory and experiment in the results described in this paper go far to indicate that the theory advanced is correct. The subject is so complicated, however, involving as it does the peculiar phenomena of the magnetization of iron, that it is manifestly dangerous to jump at conclusions in the matter. Further and more complete experiments are at present in progress in this laboratory, with the object of throwing additional light upon the subject.

Alternating Current Laboratory,
Electrical Engineering Dept.,
Columbia University,
April, 1900.

Discussion.

Mr. Steinmetz:—I am sorry to say that I cannot agree with the conclusions derived by Mr. Townsend, nor with the reasoning leading thereto. It seems to me that eddy currents in the iron of a transformer are secondary electric currents, just as any other secondary electric current, and must therefore follow the laws of electric currents; that is, the electromotive force is proportionate to the magnetic flux enclosed by the current turns, other things remaining the same. The small or large mutual induction between the secondary and primary current does not affect the law. The mutual induction between the primary and secondary may be extremely small. Take, for instance, the case of Fig. 2 on page 320, where *b a c* represents the eddy current flowing in one of the lamina of the iron. With the thickness of the lamina, and the frequency used in commercial transformers, the magneto-motive force of these eddy currents is small compared with that of the exciting current. Its M. M. F. is not noticeably affected by that of the eddy. If the magneto-motive force should be larger than the magneto-motive force of the exciting current, the same law still holds. It is true that experiment shows that the loss of energy by eddy currents does not always follow the law of squares, but deviates therefrom, but the cause of this deviation can be found. In cases where the eddy currents are large, it is the poorly laminated iron and the change in the permeability of the iron. Another cause is the high temperature coefficient of the iron causing a rapid decrease of its conductivity, thereby decreasing the energy loss. The total loss in the apparatus when started up fresh is very much larger than after it has been warmed up. Another cause is the magnetic stray field. In a revolving apparatus with considerable eddy current losses the total loss of energy is often more in proportion to the square law. The beginning of the break down of the insulation, and the decreased permeability of the iron makes the stray field, and the stray field reaches conducting masses outside of the circuit. It may very well be that these effects combined make the eddy current losses appear to follow, as stated by the paper, the law of the 1.6th power. This however appears to me an exceptional case. As a rule the eddy current losses can be calculated from the electric conductivity and the thickness of the iron. and compared with the losses found by tests over a wide range. In wattmeter readings there is a liability to constant error, which apparently changes the law followed by the losses. In Figs. 5 and 6, it rather contradicts the law of the 1.6th power. The observed value rises more rapidly than the calculated value. Now coming to the theoretical reasoning leading up to this 1.6th power, I may remark in regard to the statement on the first page, that in 1899 it was found that the phase of the exciting current of a transformer was practically independent of the frequency. I noticed that thing some years ago, and published it in 1897, that the exciting current-phase does not depend on the frequency, nor on the shape of the magnetic circuit, the length of the iron and cross-section. The formula is given on page 234 of my book. Now coming to the conclusion on page 235, leading up to the 1.6th power, " *Cb* should also be a complex harmonic current wave, similar in shape and following the same laws as those which govern the primary current." This is not the case and cannot be the case. The primary current has a very characteristic shape. It tends to a peak at the maximum point of induction, is strongly bulged out at the ascending side (making diagram). This bulging out is due only to hysteresis. The current *Cb* on pages 234 and 235, that is, the eddy current, does not expand energy by hysteresis, and therefore cannot have this bulging out at the ascending and bulging in at the descending. On the contrary, the effect is to decrease the magnetic flux. If it is distorted, the distortion should be in the opposite direction, a bulging in on the ascending side. The *Cb* does not show a bulging out at the ascending side, but is rather slightly bulged in; consequently it is in accordance with the reasoning I have just stated. Then it has not the same shape as hysteresis. This leads up to the conclusion that the energy loss of this current is proportionate to the energy loss of the exciting current, and therefore the 1.6th power cannot answer. I cannot see any reason why he should assume that the eddy currents follow the 1.6th power. Theoretically they follow the square of the frequency and the square of the induction, and may deviate therefrom by secondary effects, as change of temperature in the iron or change of conductivity and a number of other secondary effects.

Mr. Townsend:—The first part of this paper is given up to an explanation intended to account for the experimental results which are described in the latter portion of the paper. This explanation, as stated, is only offered as a suggestion. Mr. Steinmetz has said that he does not agree with it, and offers another explanation. The remarks he has made, coming as they do from so distinguished an authority on the subject, no doubt carry great weight. There are, however, certain points in connection with the experiments tending to bear out the speculations I have advanced.

In the first place, the curve of Fig. 4 is very nearly a simple harmonic, while that of Fig. 3 is plainly much distorted. These distortions seem to me, as the figure shows, to resemble those of the primary current as closely as might be expected under the circumstances. The circuit shown in Fig. 2 is not an absolutely perfect imitation of the path followed by the eddy currents in an iron sheet, and therefore it would be unfair to expect a closer agreement between theory and practice than that which appears from the curves.

The fact is also noteworthy that the current in the short-circuit shown in Fig. 3 has practically the same phase displacement as the primary current curve.

These characteristic peculiarities in the different curves were observed repeatedly, on different days and under different conditions, and there is little possibility of there being any mistake about them.

MR. STEINMETZ:—There is one very interesting fact borne out by this paper. In Figs. 3 and 4, I may say, the curve of the secondary current should be the same. The mutual induction between secondary and primary are different and the conditions are different. The conclusion that this current should be proportionate to the exciting current is not warranted, but a very interesting result is brought out. The tests agree that the result is 1.6, but theoretically we can say that there is inherent reason that they should follow the second power, but disturbing influences should make them deviate. This paper shows that owing to the phenomena where the disturbance takes place, the result is 1.6. In another case there might be a result of 1.7th power or any other power. This is a very interesting result, and a very complex phenomenon, but you cannot determine a conclusion from individual facts. If you can get a very good agreement between experiments and tests, then it is a very interesting conclusion. But going back still one step further, we know that the hysteresis loss follows the 1.6th power, but we know that is not an inherent, physical law. It must sometimes deviate from the law. It is a somewhat complex phenomenon which can be closely represented by the 1.6th power, but it is not a physical law. It shows that a very complex physical phenomenon can be represented by simple power law which is correct by approximation, over a wide range, as is shown in this paper.

PROF. GOLDSBOROUGH:—In connection with this discussion a point occurs to me which I think has been overlooked by the experimenters. I refer to discrepancies that may be observed when the fact is neglected that the distribution of flux across the core is not uniform. I will make a diagram to bring out the point that is in my mind. In a transformer core, or any other core, which, for instance, may be regarded as represented by a stamping of this shape (see Fig 9.), in view of the fact that the path followed by the flux is much shorter at E than it is at A, if we assume the average density through the section (A-E) of 2000 lines per square centimetre, we may have an actual distribution of the flux giving a density as low as 1000 lines per square centimetre at A, and as high as 3000 lines at E. These are the circumstances under which readings for hysteresis and eddy current losses in a transformer core are always obtained. Suppose now the average density is increased, what will be the distribution of the flux? The result is to make the distribution of the flux across the core somewhat more uniform, as the permeability of the iron becomes less for the higher density values. If we have an average density of 7000 lines in the core, the distribution will be more uniform than in the first case and the density starting at A, at say 6000 lines, would probably run up to a maximum of only 8000 lines at E owing to the lower permeability of the iron at E than at A. In consequence the variation in the maximum and minimum values attained by the flux are respectively less and greater than proportional to the increase in the average flux density from 2000 to 7000 lines. Consequently, if you were to measure the eddy current losses alone in this transformer core, in view of the particular effect to which I call your attention, you would find that as you increase the average density in the core, the eddy current losses would increase by an amount proportional to something less than the square of the *average* flux density. It might be the 1.9th, or the 1.8th, or the 1.6th power or less, according to the kind of iron used and the variations taking place in the flux distribution. However, the actual eddy current losses in the several paths A, B, C, D and E, would all the time be strictly in accordance with the accepted rule, and proportional to the squares of the densities actually existing along the several paths.

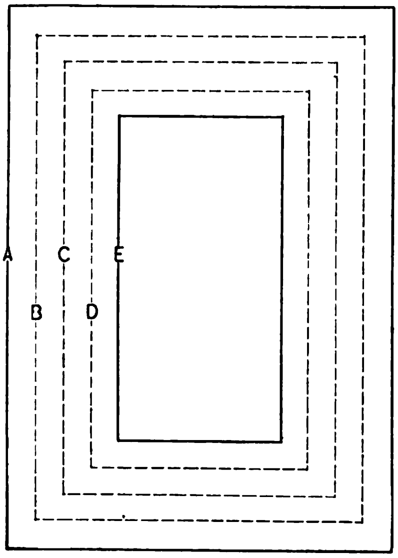


FIG. 9.

The same thing applies to the hysteresis losses. In such a core, they increase proportionally to something less than the 1.6th power of the *average* core density, owing to the flux not being evenly distributed over the core. The combined result is that neither the hysteresis nor the eddy current losses apparently increase as rapidly as is to be expected.

In the paper the author has neglected to take account of this matter, and has credited to the eddy current losses the entire discrepancy; assuming that the hysteresis loss varies as the 1.6th power of the *average* density under all conditions. As the hysteresis loss is always a more prominent factor than the eddy current loss, it is not surprising that, when the errors of measurement of both the major and minor losses are placed to the credit of the minor loss, the rate of increase in the minor, or eddy current loss, should appear very much less than proportional to the square of the *average* core density.

THE CHAIRMAN:—If there is no further discussion we will take up the next paper by Dr. Sheldon of Brooklyn, on the "Conditions of Electrolytic Corrosion in Brooklyn."

A paper read at the 17th General Meeting of the American Institute of Electrical Engineers, Philadelphia, May 17th, 1900. President Hering in the Chair.

CONDITIONS OF ELECTROLYTIC CORROSION IN BROOKLYN.

BY SAMUEL SHELDON.

The borough of Brooklyn spreads over 60 square miles, and is covered with a network of surface trolley tracks. During the rush hours about 1,100 cars run upon these tracks and are supplied with current from seven power stations, furnishing in all 47,000 amperes. Four of these are situated upon the East River water front and supply over 80 per cent. of the full load current. The currents return to the power-houses by the following paths:

First by the rails of this system, which are all bonded together, different lines employing different bonds. There are, for example, the cast weld bond, showing a conductivity of 100 per cent. or more of continuous rail, the Johnson electric weld bond, showing 85 per cent., the R. P. Brown interfoliated bond giving 94 per cent., and the protected rail bond giving varying conductivities according to size of bond and rail.

The second path of return results from the peculiar geographical position of the borough, and the peculiar conditions of the traffic. All of the car lines lead to the Borough of Manhattan. During the rush hour at 6 P. M., nearly half of the cars in operation at the time are receiving current within a radius of one mile of the Brooklyn end of the Brooklyn Bridge. At this time a large proportion of the currents are returned by way of the East River.

The third path at present takes but a small part of the current, and consists in return feeders connected with the tracks at various points.

The fourth path, which it is the intention of the engineers of the Brooklyn Rapid Transit Co. to utilize extensively along certain lines, has become available as a result of the combination of the elevated railroad interests and the trolley railroad interests. It is, namely, the whole elevated structure. This is also used at present as a return circuit for the currents used in the operation of the few third rail trains which are now upon the elevated lines.

The fifth return path consists of the mains and the service pipes of the municipal water department, the mains and service pipes of the Brooklyn Union Gas Company, the cables of the New York and New Jersey Telephone Company, and the underground tubes of the Edison Electric Illuminating Company.

These returning currents set up differences of potential between all underground conducting objects. The difference in potential between any two given points varies throughout the day, because of variations of the traffic conditions. In a similar manner it varies with the seasons, and is quite different on Sundays from what it is on week days. Furthermore, the potential differences are gradually growing smaller in the average, because of the better conductivity of the Transit company's return circuit. They are also changing because of changes in the distribution of load among the power-houses.

The difference of potential between the rails and the hydrants and the rails and the gas mains varies from a fraction of a volt to 25 volts. Between the two ends of the Brooklyn Bridge there has been a difference of potential of 20 volts. Each power-house is surrounded by equipotential curves, and in the immediate vicinity of each the fall of potential is quite rapid.

The city may be divided up into districts, each power-house drawing current from a district. The boundaries of these districts hold the same position towards the returning currents of electricity as mountains do towards the water of a watershed. The difference of potential between a point on the boundary of a district and the ground in the immediate vicinity of the power-house supplying that district has been found to reach as high a value as 40 volts.

The municipal water mains pass through nearly all streets of the city and vary in size from 48 inches in diameter down. They are all made of cast iron. Some are known as Scotch cast iron pipes. These were made in Scotland and are of a peculiarly hard and tough cast iron, which exhibits a very white surface on fracture, indicating a combination of the contained carbon. These pipes can always be recognized by ribs which occur at every two feet along the surface, and which are about four inches wide. These ribs consist of a thickening of the metal intended to furnish a firmer seating and more perfect joint for taps and branches.

Other mains are of American manufacture, are very much softer than the Scotch iron, but also exhibit a white surface on fracture. The employees of the water department prefer to work upon these mains because of the much less labor required to operate the cutting tools, owing to the relatively greater softness. In no case has an electrolytic corrosion of the water mains been discovered in the city, although many cases of corrosion of the service pipes have occurred.

The Brooklyn Union Gas Company has 755¾ miles of gas mains. These are all made of white cast iron. From them are led wrought iron service mains which are supplied with malleable iron and in some cases brass fittings. There are 272 miles of wrought iron service pipes. These with their fittings have suffered corrosion in very many cases. Thirty-eight service pipes on one block were completely destroyed in three years. However, not until within a year has any corrosion of the mains been discovered, and then in but two cases. In each case the main was in an excessively dangerous district.

The gas company claims that there has been an abnormal increase of leakage since the introduction of electric traction in 1892. The leakages for various years are not accessible, but during 1899 it amounted to 13 per cent. of the total production of 4,500,000,000 cubic feet.

The New York and New Jersey Telephone Company has many miles of underground cables, the lead coverings of which have been pitted and perforated in many cases by electrolysis. The company, however, is fully aware of the possibilities of electrolytic corrosion, keeps itself informed of its cables, and concerning the stray currents in their sheathings.

The Edison Illuminating Company has over 100 miles of underground tubing. These tubes have suffered considerably from electrolytic corrosion, doubtless resulting in many cases in the short-circuiting of the enclosed conductors.

Considering the magnitude of the system of the Rapid Transit Company, considering the time that it has been in operation (the first electric car was operated in 1892), considering the poorness of the ground return which existed on parts of the system up to within three or four years, it is surprising that no evidences of the corrosion of cast iron have been discovered with the exception of the two cases mentioned above.

The apparent immunity of cast iron was noticed by the Board of Commissioners of Electric Subways of the City of Brooklyn, and attention was called to the fact in several of their reports. These reports indicate that in their opinion the immunity was due to the peculiar chemical constitutions of the special kinds of cast iron of which the mains were constructed. It hardly seems credible that such a form of iron could exist.

To experimentally test the matter, samples of Scotch and American pipes have been obtained from the water department as well as samples of the gas mains from the gas company. These have been used as anodes in various electrolytic cells. The electrolytes consisted of samples of earth from various parts of the city, moistened in some cases with distilled water, and in other cases by hydrant water or salt water. These cells were subjected to voltages of various magnitudes. In every case the anode was corroded, showing conclusively that there is no immunity because of chemical constitution.

In preparing some experiments to determine whether or not the apparent immunity of cast iron mains was due to an electrolytic polarization E. M. F., due to absorbed gases in the pores of the rough exterior of the pipes and of sufficient magnitude to prevent the sending of any considerable current by the stray voltages, the true cause of immunity was discovered. In the casting of pipes in sand molds, the hot iron unites with a layer of the sand to form a silicious compound probably silicate of iron which forms a thin coating over the surface of the completed pipe. This coating is extremely thin, and is a non-conductor of electricity. It is not continuous, but contains perforations in many places. If a piece of pipe be covered with insulating paint, exposing only the rough sand-pocked exterior surface, and if it be made an anode in an electrolytic solution, much less current will flow through the solution under a given impressed E. M. F. than under similar conditions with an anode exposing a filed surface of equal area. In some cases, no current at all will pass until the impressed voltage rises to a certain minimum value. If, however, a current be made to pass for a few moments under a moderately high impressed E. M. F., the rough sand-pocked surface becomes conducting throughout. The protecting film or skin seems to act like the non-conducting film thrown down in an aluminium cell. The existence of a perforated skin can also be shown by endeavoring to close a circuit, which contains a current indicating device, by means of a wire on the sand-pocked surface. The end of the wire may be rubbed around in many places before there is any indication of a closed circuit. Then, again, a spot will be found where the circuit is closed, and there is no indication of resistance of any magnitude at the point of contact.

There is another thing which is perhaps equally as influential in preventing electrolytic corrosion, and that is the resistance offered by the soil. The various interested companies have observers in the field recording the potential differences between the rails and their underground system. Whenever the system is positive to the rail, the district is considered as dangerous, and corrosion is expected. It is well to notice that as corrosion will result at one side of any discontinuity of a metallic circuit, it may be expected to occur even in districts which are not considered dangerous. On the other hand, the amount of corrosion which will take place in a dangerous district under a given potential difference is dependent upon the smallness of the resistance offered by the soil. Now the measurement of the resistance of soil under laboratory conditions gives information which can hardly be applied with propriety to street conditions. It is much to be preferred that the resistance between the tracks and the other systems should be measured directly. While it is impossible to determine the resistance in such a manner as would enable one to calculate the current density at any point, and to ascertain the direction of flow lines, yet some idea of the magnitude of the ground resistance can be determined in the following method, which makes use of a low reading voltmeter (0 to 3 volts), and a battery having an E. M. F. of E volts. Let the resistance of the voltmeter be R ohms; then at any reading of the voltmeter θ, the current which is traversing that voltmeter is θ/R amperes. Now to measure the resistance between two points, for example, a point on a rail and a point on a hydrant, take the following three readings:—E', with the voltmeter alone connected between the two points; E with the battery alone connected to the voltmeter, and θ with the battery and voltmeter connected in series between the two points. The effective resistance X between the two points is determined by considering that

$$\frac{E \pm E'}{R + X} = \frac{\theta}{R}$$

whence

$$X = \frac{(E \pm E')\,R}{\theta} - R$$

$$= R\left(\frac{E \pm E'}{\theta} - 1\right).$$

For ground voltages, which are less than one volt, two cells of ordinary dry battery are sufficient. The assumption is made that the small current sent by the battery in making the measurement does not produce an E. M. F. of polarization of appreciable magnitude. This is unquestionably warranted when we consider the exposed area of the pipe or rail, and the smallness of the current. Measurements of effective resistance taken at a great many points between the hydrants of the water system and the rails in Brooklyn give values lying in the majority of cases between 10 and 35 ohms. The character of pavements seems to have no great influence on the resistance of the soil underneath. Measurements have been made in the case of asphalt, cobble stone, Belgian block, granite block, vitrified brick, and dirt roads. In all cases there were variations in resistance with different conditions under the same pavements, but the average resistance was nearly the same in all cases.

It is very probable that the current which would flow through the resistance indicated by these measurements under a given difference of potential would be distributed over a large area of pipe surface, and therefore the current density under voltages of the magnitude of those which exist in Brooklyn, would require a long time to result in destructive corrosion.

These investigations have been carried out in collaboration with Mr. Charles V. Rapelje.

DISCUSSION.

Dr. Kennelly:—I think there is another reason why the service pipes of gas and water systems are much more seriously corroded under practical conditions, than the mains, and that is owing to the fact that the joints in the mains offer a much higher resistance electrically than the joints which are made in service pipe. This is particularly the case with gas mains and services, and I suppose it is more or less true in the case of water mains and services. In the case of gas services, for instance, you find them almost invariably made with screw-joints between the ends of the lengths which are connected together. That is to say, a main may be perhaps 30 or 40 or 100 feet from the meter, and the pipe which connects the meter with the main is a small pipe, screwed together in sections, and the screw-joints are fairly good electrically, so that there is very little resistance in that pipe. On the other hand, the mains, which may be in ten feet sections, are connected together by joints which are electrically very inferior. In order to send a current through a system of mains you have to loop the current in and out at each joint, to a very considerable extent. A current through a main pipe can therefore only be powerful in the presence of a considerable difference of potential; whereas the current in a service pipe may be powerful with a relatively small difference of potential. The difference of potential mentioned in this paper is enormous and ought not to exist in any well planned system.

In any well-constructed system of electric railroad. with well bonded track and return feeders, the potential difference can be reduced to any reasonable amount that the expense will warrant.

Mr. R. T. Lozier:—Some time ago some one advocated an auxiliary machine which would so adjust the potential as to make the water mains the cathode, and the rails the anodes, thus depositing from the rails on to the pipes instead of vice-versa. I should like to ask Dr. Sheldon if this has been a success.

Dr. Sheldon:—The legal status of the companies in Brooklyn is rather peculiar. In the first place, the men who own the electric lighting company also own the railroad, and I believe there is something in the wind as to the getting control of the gas company. The municipal water department has a bond from the electric railway company, securing the former against any damages which may occur from electrolytic corrosion. Therefore the water department will not permit any bonding of its system of pipes, nor will it permit any electrical devices to be connected with them. I would like to say in reference to Dr. Kennelly's remarks that although the main pipes have a large resistance at the joints there is no question but what a large current flows through the pipe. In the case mentioned in the paper of 38 service pipes having been destroyed in three years, the conditions were rather peculiar. The Brooklyn Union Gas Company is formed out of various companies that have been consolidated. This corrosion of the service pipes was near the Broadway ferry where a great many cars run during the rush hours. The ferry is near the Kent Avenue power station. Down Broadway, on one side of the street, comes one gas main which then turns the corner and runs towards the power station, coming down the same street on the other side is another gas main which turns the corner and goes in the opposite direction. To this other main were connected the 38 service pipes. In entering the building of customers the service pipes passed over the first main and were corroded at the place where they passed over. The current, which was carried by the main with which they were connected, was returned to the power house by the other main, and the rapid destruction was avoided under the advice of their electrical engineer by simply connecting the service pipes to this other main rather than the first. [Adjourned to Friday, May 18th, 1900 at 10 A. M. when discussion was continued.]

MR. CHARLES J. REED:—I do not wish to take very much time, as there are a good many papers to be read this morning, but there is one point in this connection which seems to be almost always ignored, and I think it is an important one; that is the fact that it really requires no electromotive force to cause a current to enter and emerge from an iron pipe buried in the ground. An infinitesimal electromotive force will make the current pass into the iron pipe and out in preference to going through the earth. This is due to the fact, as we all know, that the ground is a conductor solely in consequence of the fact that it contains water and saline solutions, and that wherever a current passes from an electrolyte or to an electrolyte there is electro-chemical action. The current passing to an iron pipe from an electrolyte in solution, that is, containing water, will always evolve hydrogen if there is no other chemical reaction possible there which requires the absorption of less energy. If the point at which the current leaves the pipe is capable of supplying by its electro-chemical action an equal amount of energy or a greater amount, a current will pass in and out of the pipe in preference to passing through the electrolyte itself. In the case of iron, the oxidation of iron to ferrous hydroxide, evolves 68,900 calories of heat. The decomposition of water requires, of course, the same energy which is evolved in its formation, and that of liquid water is 69,000. This amount of energy must be supplied in order to effect the evolution of hydrogen and enable the current to pass in and out of the pipe. But as 408 calories must necessarily come from outside and be absorbed in the form of heat (since that is used, not electrolytically, but in expanding the evolved gas to atmospheric pressure), it leaves the amount necessary to actually decompose water 68,596. The equivalent electromotive force, required to evolve hydrogen is 1.47 volts, and that which the oxidation of the iron produces is 1.48. So that instead of an electromotive force being required to drive this current through the iron pipe, the passage of the current through the pipe produces a slight electromotive force; that is, there is some electromotive force added to the circuit and there is a tendency for the current to flow through the pipe in preference to flowing in the earth near the pipe and parallel with it. This, of course, increases the effect which Dr. Kennelly called attention to yesterday, of the current flowing in and out around an insulating joint, or a joint of even a very little resistance; but it must not be supposed that this passage of the current in and out is limited to the joint or to the neighborhood of the joint. If there is a current flowing through the earth in a direction parallel with a piece of iron pipe, or any other piece of iron, a large portion of the current will enter the iron and pass out. We might suppose that where the current passes in there would be a tendency to reduce the oxide of iron already formed there instead of evolving hydrogen. The very fact that the formation-heat of the iron oxide is greater than that of the hydrogen oxide, shows that the iron will not be reduced; and even if it were reduced, its tendency to oxidize is so great especially in the divided form, that it would not stay reduced. The corrosion would therefore go on as if there were no reduction. As a matter of fact there could be no reduction under those circumstances, unless there was a very considerable electromotive force, that is, a very powerful current. And such reduction, if it occurred, would not retard corrosion.

Mr. Ludwig Hommel:—One or two points occurred to me during the reading of this paper. In some cases we notice cables and pipes may be negative to the earth and still be positive to the rails. This must be due to the condition of the rail system, there probably being a break or bad connection in same somewhere further away from the station, and a good connection with the negative side of the dynamo from the place where that is observed. I see no reason why electrolytic action should take place in such places as that. Also another point occurred to me, bearing on the protection of underground cables. I see that Dr. Sheldon gives several paths by which the current returns to the power-house. There is one path which may be used in some instances and which I do not see mentioned here, for protecting the cables. In some telephone construction the ærial cables are spliced directly to the underground cables, and while this may not be advisable on account of the danger of burn-outs in the underground system, in case the overhead system should become crossed with trolley wires or electric light wires, the lead covering of these ærial cables can be used as a special return to lead back the current from the underground cables to the power-house, wherever the ærial cables run toward the power-house and copper can be saved by doing so. It is a small point but very often it saves copper, and it might be interesting.

The President:—If there is no further discussion we will proceed with the next paper on the list, by Dr. Perrine and Mr. Baum, on "The Use of Aluminium Line Wire and Some Constants for Transmission Line."

A paper read at the 17th General Meeting of the American Institute of Electrical Engineers, Philadelphia, May 18th, 1900. President Hering in the Chair.

THE USE OF ALUMINIUM LINE WIRE AND SOME CONSTANTS FOR TRANSMISSION LINES.

BY F. A. C. PERRINE AND F. G. BAUM.

Until the present time, discussions of the use of aluminium wire in line construction have been devoted to a consideration of the relative prices of copper and aluminium wires, the conductivity, tensile strength and other proportions of the aluminium wire being only considered as determining its relative price. During the past year the manufacturers of aluminium have demonstrated their ability to sell this wire at a price well below twice the price of copper per pound, and in consequence the new material has forced itself upon our notice and has demanded that we consider carefully all of its properties independent of any consideration of price. Having recently been forced into the purchase of a considerable amount of this wire by reason of the high price of copper and the low price of aluminium, the writers have made a careful study of the wire supplied, and now present the results obtained in hope that they may be of service to other engineers.

Some of these results have already been published,[1] but in these publications there have been so many misprints that it seems advisable to present the whole matter anew. The line for which this wire was purchased is about forty-three miles in length, and the country through which it runs varies in elevation from about one hundred feet above the sea level to at least two thousand feet; one-half lying in almost a straight line through

---

[1] Tests and Calculations on a Forty Mile Aluminium Transmission Line. F. A. C. Perrine, Pacific Coast Transmission Association.

a country almost level, while the remainder is over the mountains, through which the line runs almost straight, surmounting high hills and descending into deep gulches. In some cases the lengths of the poles were proportioned to decrease the vertical line deflection, but as an accurate preliminary survey was not available, much less grading of poles was possible than would have been desirable. This defect in pole setting was largely counteracted in the wire stringing by the drawing of a number of spans at one time, so that at depressions and elevations there was very little up or down strain put on the wire when it was tied to the insulators. The standard pole used was of square sawn redwood, thirty feet in length, seven inches square at the top, and tapering to twelve inches square at the butt, or about eleven inches at the ground line five feet above the butt. Each pole was gained for three cross-arms 20½ inches on centers, the gains being cut ¾ inch deep, into which the cross-arms were bolted by single ⅝ inch through bolts. The arms themselves were 4x4 inch Oregon pine bored for two pins each, the top and bottom arms being three feet in length and the center arm four feet. The wires on this system of construction are arranged in a hexagon, each side being 24 inches in length.

This system of construction presents some advantages for three-phase working at high voltages for long lines, especially where the two sets of circuit are to be operated from the same bus bars. If both of the wires on each arm are at the same potential, the arrangement of each circuit is that of an equilateral triangle, each side being 41 inches, while the minimum distance for leakage between any two wires of different phases is 36 inches of cross-arm and 20 inches of pole, while the length of the longest arm necessary is much less than that in any other system of construction; the pole head is symmetrically loaded, and for these reasons the pole construction is exceptionally stable under all stresses.

The insulators used were a flat topped glass, triple petticoat type, about five inches in height and seven inches in diameter, with a wire groove of about .35 inches radius. The insulators are supported by eucalyptus pins of a length to give a distance of four inches between the bottom of the insulator petticoat and the cross-arm, eucalyptus wood having been used on account both of its availability in California for a special pin, and on account of its great strength, which is of extreme importance in the construction of pins of such length.[1] For further insulation and preservation, the cross-arms used were creosoted by a treatment in which the timber was at first dried carefully and then injected with ten pounds of dead oil of coal tar to the cubic foot, an operation requiring approximately thirteen hours for its completion, while the pins were boiled at a temperature of about 225° F. for about eight hours in a compound of coal tar and asphaltum, a treatment which gave a better external surface than the creosote. This latter coating did not penetrate the wood materially, but after experimenting extensively with this wood at temperatures up to 225° F. and pressures up to 160 pounds per square inch without effecting any appreciable penetration of this wood, either with creosote or other extremely fluid materials, all idea of the use of a penetrating compound was abandoned, and an endeavor made to obtain a coating which would provide the most complete external protection.

On this line as erected, the arms were braced by a bent angle iron brace, but this precaution seems now to be entirely unnecessary, and a subsequent line belonging to the Yuba Power Co., erected on much the same plan, is not braced at all. For arms of over five feet in length a brace is certainly advantageous, though it is the opinion of the writers that for high potential service the braces should be of wood mortised into the cross-arms and nailed to the pole face.

The above complete physical details of the construction are unnecessary for the discussion of aluminium line wire, though it is believed that its stability when erected depends upon a careful study of all such conditions.

The line as erected carried only four wires arranged on the top and bottom cross-arms, thus taking their location at the corners of a rectangle 24″ on the short side and 41″ on the long side. This arrangement was adopted for the purpose of making temporary use of some two-phase machinery which was in place and underloaded, allowing certain new customers to be taken on quite a year in advance of the contemplated completion of a three-phase plant for which the pole line was really designed.

It was at first feared that this arrangement of the wires would result in inductive disturbances between the phases, as the wires

---

[1] Tests of a considerable number of pins made of eucalyptus, oak and locust show that the eucalyptus has about 20 per cent. more strength than locust and 80 per cent. more than oak.

took their positions in the diagonally opposite corners of a rectangle, in place of the corners of a square, as is necessary for complete absence of mutual induction, but the anticipated trouble was not found. Careful measurements were made with one phase short-circuited and the other carrying about 20 amperes with a periodicity of 60 cycles per second, both with a Weston 75-volt voltmeter and a Rowland electro-dynamometer, with the result that no deflection was observable on the voltmeter, while the current read on the electro-dynamometer amounted to only about .001 ampere, the resistance of the dynamometer being 25 ohms and of the line 90 ohms. Only one additional question of installation needs attention, which is the presence on the tops of the poles of a barbed wire stapled to the wood of the pole and grounded at every fourth pole by a galvanized iron wire leading down along the pole and soldered to an iron plate 18 inches square and ⅛ inch thick, set in the pole hole immediately under the foot of the pole itself. This wire was intended as a lightning guard, and it has apparently done very effective service in discharging the line in all weather.

The wire used was intended to be equal to No. 3 B and S copper wire in its electrical resistance, and the manufacturers were required to furnish this conductivity in a wire not weighing more than 420 pounds per mile. All the wire supplied was carefully inspected by Dr. A. E. Kennelly, and his reports give the following averages for the total quantity:—

Diameter	293.9 mils
Wt. per mile	419.4 lbs.
Resistance per mil foot	17.6 ohms at 25° C.
Resistance per mile at 25° C	1.00773 ohms
Conductivity compared with copper	59.9% by dimension
Tensile strength of wire	1549 lbs.
No. of twists in six inches for fracture	17.9
Tensile strength per square inch	32898

Comparing this with copper it is seen that this wire is approximately the same as copper in the following sizes:—

Size of aluminium wire = No. 1 B & S copper
Resistance of " " = No. 3 " "
Tensile strength " " = No. 5 " "
Weight of " " = No. 6 " "

Therefore on the basis of the same conductivity the aluminium compares with copper as follows:—

Diameter	for the same conductivity	1.27	times copper
Area	" " " "	1.64	" "
Tensile strength	" "	.629	" "
Weight	" "	.501	" "

The mechanical properties of this wire present some well marked characteristics. In the first place, the number of twists necessary for fracture varies considerably, although the ductility test of wrapping six times around its own diameter, unwrapping and wrapping again is well sustained. This irregularity in the twisting test is generally a mark of impurity in wire, but we know so little as yet of the exact characteristics of aluminium in particular, and the twisting test is in general so unreliable that it is unsafe to base any exact statement on this one test, particularly as the same after erection proved reliable. In carefully performing the test for tensile strength no exact point could be assigned for the elastic limit, as the metal seemed to take a permanent set almost from the first, but at a stress of from 14,500 pounds to 17,000 pounds per square inch, there is a marked increase in the permanent set which indicates that the safe working load lies somewhere in this region. In this the characteristics of the aluminium do not differ materially from those of copper or other similar metals, and while this is a disadvantage it is not a singularity.

The fact that the wire will permanently elongate if seriously strained, makes it necessary to use the utmost care in the erection of lines, and also the known high coefficient of expansion with temperature changes taken in conjunction with this property renders care in line stringing especially important and difficult.

For the purpose of ascertaining exactly what were the changes with temperature that might be anticipated, the Pittsburg Reduction Company undertook a series of experiments by means of the observation of 200 feet spans of wire at temperatures varying between 6° F. and 55° F., and at the same time the authors carried on a similar series of experiments on a 150-feet span at the Leland Stanford, Jr. University in which the temperatures varied between 20° F. and 80° F. From the results of these experiments a coefficient of expansion with temperature was obtained, which was used in calculating sets of tables for the instruction of the line foreman which gave the tensions and deflections at the different temperatures encountered. These tables were calculated by use of the ordinary approximate formula for the tensions and deflections of a suspended wire, and the method used for obtaining the coefficient of temperature expansion removes the usual objection to the formulæ that they do not take into account the elasticity of the wire itself, which produces serious errors if an attempt be made to use the true coefficient of linear expansion by changes of temperature. In fact, the coefficient of linear expansion obtained from these experiments is less than one-half the value of the true coefficient of linear temperature expansion, but its use is justified by the fact that the tables as calculated have been frequently verified experimentally, both at the testing stations and in the field, while the line was being strung. A comparison of the calculated and observed results obtained by the Pittsburg Reduction Co. is given below in Table No. I. As a result of these tests the above-mentioned company have issued a table of deflection tensions and temperatures which is given in Table No. II.

TABLE I.

COMPARISON OF OBSERVED AND CALCULATED DEFLECTIONS OF ALUMINIUM WIRE.

Temp.	C	D	G	H
0°	21 20⅜	20¼ 20⅜	20⅛ 20⅜	20¼ 20⅜
10°	24¼ 24⅞	24 24⅞	24 24⅞	24 24⅞
20°	28 28¾	26⅝ 28¾	26⅞ 28¾	27 28¾
30°	31⅜ 31⅛	30⅛ 31⅛	30⅜ 31⅛	30⅜ 31⅛
40°	34¾ 35¼	34½ 35¼	34⅝ 35¼	34¾ 35¼
50°	37¾ 38¼	37½ 38¼	37¼ 38¼	37½ 38¼
60°	41¼ 40¾	40¾ 40¾	40¾ 40¾	41 40¾

C = No. 2 × B Aluminium wire
D = No. 2 Pure " "
G = No. 10 × B " "
H = No. 10 Pure " "

February 4th, 1899.

Upper figure is the Observed Deflection.
Lower " " " Calculated "

From the results of the experiments made at the Stanford University a table was calculated in accordance with which the line under discussion was strung. Table No. III.

Attention must be called to the fact that while the minimum temperature given in the table used in California is + 20° F.,

TABLE II.

Table of Deflections and Tensions for Aluminium Wire.

X = Deflection in inches at centre of span. S = Factor which, multiply by weight of foot of wire to obtain tension. Maximum Load = 15,000 per square inch.

	t = −20°		−10°		0°		10°		20°		30°		40°		50°		60°		70°		80°		90°	
Span	S	X	S	X	S	X	S	X	S	X	S	X	S	X	S	X	S	X	S	X	S	X	S	X
80	12940	¾	1660	5⅜	1176	8⅛	961	10	833	11⅛	781	12⅛	680	14⅛	630	15¼	589	16⅜	555	17⅝	527	18¼	502	19⅛
100	12940	1⅛	2083	7¼	1470	10¼	1202	12½	1042	14⅝	933	16	869	17¾	768	19	735	20⅝	695	21½	658	22¾	628	23⅞
120	12940	1⅝	2500	8⅝	1768	12¼	1400	15⅝	1251	17¼	1120	19¼	1022	21⅛	946	22⅞	885	24⅝	835	25⅞	792	27¼	755	28⅝
150	12940	2⅝	3038	11⅛	2540	14⅛	1788	18⅞	1552	21¾	1390	24	1265	26⅝	1177	28⅝	1060	30⅝	1039	32⅛	987	34¼	941	35⅞
175	12940	3⅛	3643	12⅝	2576	17⅞	2104	21¾	1822	25¼	1630	28½	1488	30⅛	1377	33⅝	1279	35⅞	1215	37¾	1152	39⅞	1099	41¾
200	12940	4⅝	4206	14¼	2947	20⅝	2403	24⅞	2084	28¾	1930	31⅛	1672	35¼	1574	38¼	1473	40¾	1393	43	1316	45⅛	1256	47¾

TABLE III.

Tension and Deflection Tables for Line Construction.

T = pounds. h = inches. t = temp. of wire. Oct. 17, 1898. Tension and deflections for No. 1 Aluminium wire. (Wt. 420 lbs. per mile.)

	t = 20°		30°		40°		50°		60°		70°		80°		90°		100°		110°		120°	
Span	T	h	T	h	T	h	T	h	T	h	T	h	T	h	T	h	T	h	T	h	T	h
80	1025	¾	149	5¾	106	7⅝	84	9⅛	77	10⅛	65	11⅝	59	12⅞	55	13⅞	51	14⅞	48	15¾	45	17
132	1025	1¼	220	8⅞	166	13⅛	138	15	119	17⅝	107	19½	97	21⅝	91	23	81	24⅝	80	26⅛	73	27⅞
200	1025	4⅝	427	14¼	311	19¼	258	23⅛	221	26¾	200	30	184	32⅛	170	35¼	157	37⅞	150	39¾	143	41¾

that given by the Pittsburg Reduction Co. is = —20° F. These different minimum temperatures are made necessary by the conditions under which the wires are to be strung, and they indicate merely the starting points of the tables; counting from this point it is seen the maximum difference in deflection for the two tables is 4¾ inches for the 200-feet span at a temperature rise of 100 degrees above the minimum. While this difference in deflection is not beyond the errors in the thermometer and deflection observations in the field, it is the belief of the writers that Table No. II is the more reliable on account of the fact that it was deduced from a larger series of observations made under the more favorable circumstances.

A copy of Table No. III together with the following instructions was issued to the line foreman, who was also provided with a thermometer, a dynamometer and a pair of targets for measuring the deflections.

Instructions to line foreman in stringing wires:—

1. All spans are to be strung with deflections and tensions as specified in table.

2. Up and down hill spans to be sprung to correspond with level spans. In case level spans cannot be used, then employ dynamometer, and ease all wires over cross-arms.

3. All ties are to be made at one time by signal.

4. All ties are to be made by crossing wires around insulator serving three times around wire, and twisting behind insulators; the ends of the tie-wires are not to be cut, but bent back toward insulators.

5. Tie all wires on the outside of the insulators, except at corners where all are to be tied so that the strain is against the insulator.

6. Joints are to be made by means of sleeves twisted two and a half times, the ends of the wires being given one turn by hand around the wire. No tools are used, except in twisting the sleeves and cutting off the ends of the wires. Before inserting the wire in the sleeve, the ends of the wire must be roughened by draw filing.

7. Barbed wire is to be laid along the roofs of the poles and held by three staples driven in tight, but without kinking the wire. Ground wires are to be soldered to the barbed wire and at the bottom of the pole to the wire leading from the ground plate. All soldering acids must be carefully washed away after the soldering is done.

8. Beginning between poles one and two, all wires are to be barreled by shifting one pin, and same to be repeated between poles 21 and 22 and 41 and 42, and so on. Barreling always in the same direction of twist every twenty poles. A record must be kept of the location of every wire and every pole.

General Caution.—The greatest care must at all times be taken against kinking or scarring the wire; wherever the wire is accidentally kinked or scarred it must be cut and spliced.

The targets mentioned above consisted of light sheet iron strips about two feet long and two inches wide, with an aluminium hoop bent into an eye at the top, by means of which they could be hung from the line wire. These targets were painted in three or four colors, with bands one inch wide. In use, the captain of the linemen would hang his target on the wire to which a man on the next pole had also hung a target; then, as the wire was being pulled into place, he would sight from a band on his target to the same band on the adjacent target, and when the wire came into line with these two bands the signal would be given for all the linemen to tie at once. As a result of this method of stringing, an exceedingly uniform line and one strong in accordance with the temperature was obtained.

One of the most serious problems in connection with the use of aluminium is in the choice of a proper joint. This metal is so highly electro-positive that it is unsafe to expose it to the elements in contact with any other material, as electrolytic corrosion is almost sure to follow such construction. Many of the failures which have been reported of this metal have been due to a neglect of this fact; as notably in the case of the plates on the yacht *Defender*, where the plates have been corroded at the contact with the bronze rivets used in fastening them to the frame. Whenever this metal is soldered or used in contact with any other metal, the joint should be thoroughly waterproofed to prevent such action. After discussing many joints, it was finally determined to abandon any attempt to solder or clamp the wire in any manner, and the joints were made by slipping the ends of the wire into an oval aluminium tube about nine inches long, which was then twisted with a pair of clamps similar to those employed in twisting the McIntire connector. After twisting the tube a turn was taken by hand of the loose ends and the wire cut off close. The joint produced proved practically equal to the original wire in both tensile strength and electrical conductivity.

This wire was erected during the winter of 1898–99, which was an unusually open winter over the whole State of California, allowing practically continuous construction work, though the temperature varied all the way from about 30° F. to 80° F. at times when the wire was being strung. After it was finally erected it remained about three months on the poles before the machinery was delivered and put in place. During the first month of that time three breaks occurred which were all apparently due to flaws in the material, but after these breaks were repaired the line wire gave absolutely no trouble whatever, though various accidents occurred to other parts of the construction. Many insulators were shot at and broken, bale wire and bale rope was thrown over the line, a twig short-circuited one phase and fell down burned, a large bird was killed by contact with the wires, and finally several porcelain insulators with porcelain pins were broken off and hung suspended by the wire. In January and February of the present year this whole line was taken down to give place to a much heavier one of the same material, an opportunity for such a total change having been found after the total destruction of the power-house by fire last November.

During the past two years other lines of aluminium wire have been erected on the Pacific coast, all but one of which have given a considerable amount of trouble from causes that are not entirely apparent.

One line in Nevada County, erected at about the same time as that we have been describing, and for which the wire was of practically the same lot, has given no trouble whatever.

The power transmission lines of aluminium wire about Seattle have broken a few times, but have not given serious trouble. The breaks in this line, so far as the writers have been informed, seem to have been due to not allowing enough sag at the higher temperatures, and a consequent overstraining of the wire in cold weather.

The most serious difficulties have been encountered by the telephone company in Washington and Oregon and by the Yuba Power Co. In all of these cases it seemed almost impossible to keep the wires on the poles in certain sections, and in these sections the lines have been finally taken down and replaced by other wire of either copper or aluminium. The writers have examined many breaks from these lines, and would judge, from the appearance of the fracture, that the cause, whatever it may be, was similar. In those breaks there are many small flaws, but by far the greatest majority are clear, sharp fractures, with but a slight reduction of area, and that entirely on one side, a break very characteristic of improperly mixed and brittle alloys. Partially from the appearance of the fracture and partially from the facts that the breaks occur only in certain sections of the line, the writers are of the opinion that this trouble is due to the presence of impurities in the material. This view is strengthened by the fact that when measurements were made on the line of the Yuba Power Co., the resistance of the whole line was found to be 10 per cent. greater than it should have been if it were made of the quality of material described in the earlier part of this paper. Furthermore, in one-half of this line there were no breaks at all due to defects in the wire itself.

As a general conclusion, it is the opinion of the writers that aluminium can be safely used in place of copper where the proper precautions are taken in inspecting the wire before it is erected, and in erecting it with due consideration of its peculiar properties of low and indefinite elastic limit, high coefficient of temperature expansion and active electrolytic power.

Indicating our faith in this opinion, it may be noted that for the new line soon to be erected an aluminium strand ¾ inch in diameter has been ordered. This strand will be spliced with aluminium sleeves, and in the whole construction about one million pounds of aluminium will be employed.

EXPERIMENTAL AND MATHEMATICAL DETERMINATION OF LINE CONSTANTS.

Opportunity was given to test the line described above and also another aluminium line 62 miles in length, No. 4 B. and S. wire. These lines were tested for capacity, self-induction, mutual induction, ohmic resistance and insulation.

As there has been some difference of opinion among electrical engineers as to the charging current or capacity current of a three-phase line, great care was taken to accurately determine the capacity of a line when arranged, as is usual in practice, with the wires on the corners of an equilateral triangle. If the line capacity may be considered as connected between the wires Δ, the charging current in one wire would be $\sqrt{3}$ times the charging current of a single-phase line for the same voltage and distance between wires. On the other hand, if the line capacity is star connected, the charging current of one wire would be $\frac{2}{\sqrt{3}}$ times the charging current of a single-phase line for the same voltage and distance between wires. To determine which of the above is the correct assumption, it was only necessary to charge the three wires with three-phase potential and measure the current in one wire, then disconnect one wire from the potential source and read the ammeter again. All the measurements indicated that the line capacity is to be considered as star connected.

The method used to determine the line capacity was to insulate one end of the line and to charge the line with three-phase potential from the other end. To measure the potential applied, a Weston 150-volt voltmeter, which was checked before and after the experiments, was used. To measure the current a special Rowland electro-dynamometer was used. The instrument was calibrated and frequently checked in the position used, by sending a current through it and a known non-inductive resistance by a known potential difference. The leakage current over the insulators could be neglected. For convenience, safety, and to eliminate errors, a low potential, 130 to 200 volts, was applied to the line and the ammeter connected directly in series with one line wire. The results obtained for the capacity of a three-phase line experimentally agree with those obtained by calculation. No disagreement with the conclusion has yet come to our notice, although the charging current has been subsequently observed with voltages as high as 25,000, and no disagreement is expected in the line at present being erected; the potential of the line is to be above 40,000 volts between wires, the wires being $\frac{3}{4}''$ aluminium cables with 42″ between centers.

The method used in making these calculations—which is here given—is believed to have an advantage of simplicity over the method due to Oliver Heaviside, now generally used for calculating the electro-static capacity of transmission lines. It will be found to give a solution for all cases found in practice with little labor.

In calculating the capacity of a condenser, the plates are assumed charged with equal and opposite quantities of electricity and the potential difference between the plates is calculated;

the capacity of the condenser being defined as the ratio of the quantity of electricity on one of the plates to the difference of potential between them.

Take, first, the simple case of two wires suspended in free space, Fig. 1. Charge wires with $+Q$ and $-Q$ units of electricity per unit of length of line. The potential difference between wires A and B may be found by moving a unit quantity of electricity from the surface of A to the surface of B, or, since there is a plane of zero potential midway between A and B, we may move the unit charge from O to the surface of B. This will give the capacity between B and the mid-plane.

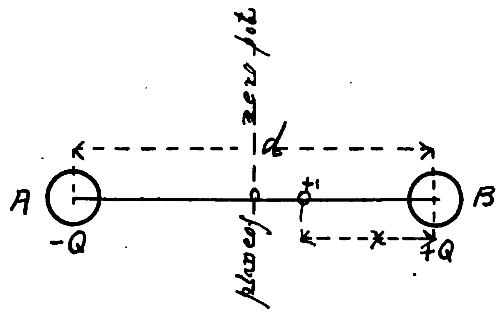


FIG. 1.

The force acting on the unit quantity at the distance x from B is

$$F = \frac{-2Q}{x} - \frac{2Q}{d-x} \tag{1}$$

Multiply by $-dx$ and integrate between the limits $x = \frac{d}{2}$ and $x = r$ (r = radius of wire).

We get

$$V = \Big[2Q \log x\Big]_r^{\frac{d}{2}} - \Big[2Q \log (d-x)\Big]_r^{\frac{d}{2}}$$

$$= 2Q\left(\frac{d}{2}\right) - 2Q \log (r) - 2Q \log\left(\frac{d}{2}\right) + 2Q \log (d-r)$$

$$= 2Q \log\left(\frac{d-r}{r}\right)$$

Or, since for aerial lines r is small in comparison with d, we have $V = 2Q \log \left(\frac{d}{r}\right)$, and the capacity in electro-static units between B and the mid-plane per unit length of line is

$$C = \frac{1}{2 \log_e \left(\frac{d}{r}\right)} \tag{3}$$

The total potential between the two wires is

$$V = 4Q \log_e \left(\frac{d}{r}\right)$$

and therefore the capacity between the wires

$$C_{ab} = \frac{1}{4 \log_e \left(\frac{d}{r}\right)}. \tag{4}$$

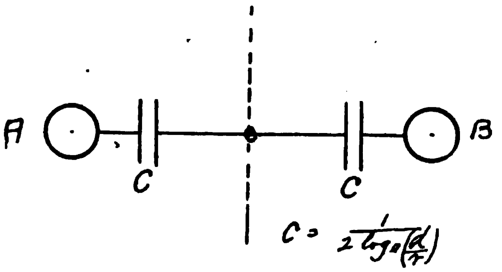


FIG. 2.

It will simplify matters some when we come to multiphase circuits to consider the capacity C_{ab} between the two wires as made up of two capacities, C equation (3), connected in series from A to B, as in Fig. 2.

From the above proof it follows that in calculating the capacity of different systems the following general proposition may be made regarding the work done in moving unit quantity of electricity from one point of an electrostatic field to another, the field being due to a charged wire, the wire being considered infinite in length:

The work done in moving unit quantity of electricity from one point of an electric field to another against the force due to *a charged wire is equal to twice the quantity of electricity on the wire times the logarithm of the ratio of the initial to the final distance of the unit charge from the wire. If there are several wires in the field the algebraic sum of all the terms formed as above will give the work; the sign of each term is determined by the sign of the quantity of electricity on the wire in question.*

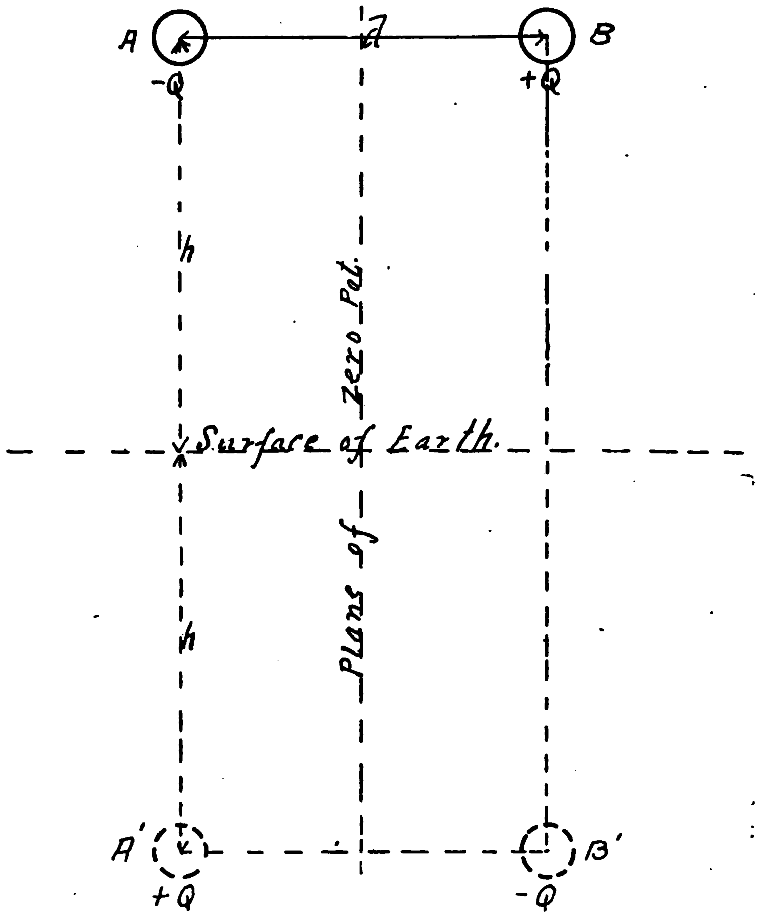


FIG. 3.

As an illustration of the above let us find the effect of the earth on the capacity of two wires distanced h above its surface, Fig. 3. Move the unit quantity of electricity from the surface of A to B.

The work done against the force due to A is

$$-2Q\log\left(\frac{r}{d}\right)=+2Q\log\left(\frac{d}{r}\right);^{*}$$

the work done against B is

$$+2Q\log\frac{d}{r};$$

the work done against A[1] is

$$+2Q\log\left(\frac{2h}{\sqrt{(2h)^2+(d)^2}}\right)=-2Q\log\left(\frac{\sqrt{(2h)^2+d^2}}{d^2}\right);$$

the work done against B[1] is

$$-2Q\log\left(\frac{\sqrt{(2h)^2+d^2}}{d^2}\right)$$

The potential between A and B is the sum of the above four terms; this gives us

$$V=4Q\left[\log\left(\frac{d}{r}\right)-\log\Bigl(\sqrt{1+\left(\frac{d}{2h}\right)^2}\right],\text{ giving}$$

$$C=\frac{1}{4\Bigl[\log\left(\frac{d}{r}\right)-\log\Bigl(\sqrt{1+\Bigr)\frac{d}{2h}\Bigr)^2}} \tag{5}$$

As will be seen by comparing with equation (4) the influence of the earth on the capacity of aerial lines may be generally neglected.

Whenever the wires of the circuit are symmetrically placed with respect to a plane, this is a plane of zero potential; whenever the wires are placed symmetrically with respect to a line, this will be a line of zero potential. It is assumed in the above that there are no other wires very near the wires of the

---

* This should be $-2Q\log_e\left(\frac{d-r}{r}\right)$, but r may always be neglected in comparison with d for aerial lines. This assumption is made throughout the paper.

circuit. In such cases—practically all transmission lines—it is usually simpler to calculate the capacity between one wire and the plane of zero potential or between one wire and the line of zero potential.

Three-phase transmission lines are usually arranged with the wires on the corners of an equilateral triangle , this arrangement gives a line of zero potential at the center of the triangle. For this case we may calculate the capacity between one wire (A) and the center point O, Fig. 4. The instantaneous quantities of electricity on wires A, B and C will be $Q \sin \omega t$, $Q \sin (\omega t - 120^\circ)$ and $Q \sin (\omega t - 240^\circ)$ respectively. With the aid of the above corollary, calculate the work done in moving unit charge from O to A.

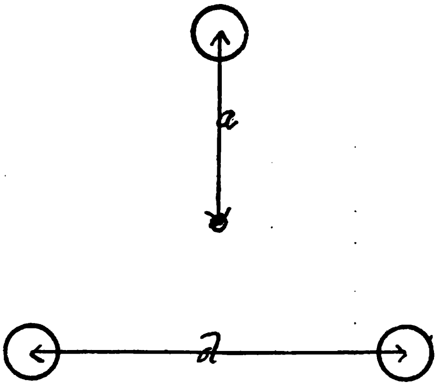


FIG. 4.

This gives

$$V = 2Q \sin \omega t \log \left(\frac{a}{r}\right) + 2Q \sin (\omega t - 120^\circ) \log \left(\frac{a}{d}\right) + 2Q \sin (\omega t - 240^\circ) \log \left(\frac{a}{d}\right)$$

$$= 2Q \sin \omega t \log \left(\frac{d}{r}\right);$$ and the capacity per unit length of line is

$$C = \frac{1}{2 \log_e \left(\frac{d}{r}\right)};$$ the same result for B and C.

The result gives the capacity arranged as in Fig. 5, which agrees with experiment.

TABLE IV.

Capacity in Micro-Farads and Charg. Cur. per mile of circuit for three-phase system.

Line E.M.F.—10,000 volts. 60 P.P.S.

Size B. & S.	Diam. in inch.	Distance d in inch.	Capacity c M. F.	Charg. cur. in Amperes	Size B. & S.	Diam. in inch.	Distance d in inch.	Capacity c in M. F.	Charg. cur. in Amperes
0000	.46	12	.0226	.0492	4	.204	12	.01874	.0408
		18	.0204	.0447			18	.01726	.0377
		24	.01922	.0418			24	.01636	.0356
		48	.01474	.0364			48	.01452	.0317
000	.41	12	.0218	.0474	5	.182	12	.01830	.0399
		18	.01992	.0414			18	.01690	.0368
		24	.01876	.0408			24	.01602	.0349
		48	.01638	.0356			48	.01426	.0311
00	.365	12	.0214	.0465	6	.162	12	.01788	.0389
		18	.01946	.0423			18	.01654	.0360
		24	.01832	.0399			24	.01560	.0342
		48	.01604	.0349			48	.0140	.0305
0	.325	12	.02078	.0453	7	.144	12	.01746	.0389
		18	.01898	.0413			18	.01618	.0352
		24	.01642	.0379			24	.01538	.0335
		48	.01570	.0342			48	.01374	.0290
1	.289	12	.02022	.0440	8	.128	12	.01708	.0372
		18	.01952	.0403			18	.01586	.0341
		24	.01748	.0380			24	.01508	.0328
		48	.0154	.0337			48	.01350	.0294
2	.258	12	.01972	.0372	9	.114	12	.01660	.0364
		18	.01818	.0305			18	.01552	.0337
		24	.01710	.0372			24	.01478	.0317
		48	.01510	.0328			48	.01326	.0289
3	.229	12	.01938	.0421	10	.102	12	.01636	.0356
		18	.01766	.0385			18	.01522	.0329
		24	.01672	.0364			24	.01458	.0310
		48	.01480	.0322			48	.01304	.0284

Basis of Table.

$$C = \frac{1}{2 \log_e \left(\frac{d}{r}\right)},$$

in electro-static units per cm. of circuit.

$$C = \frac{0.0776 \times L}{2 \log_{10} \left(\frac{d}{r}\right)},$$

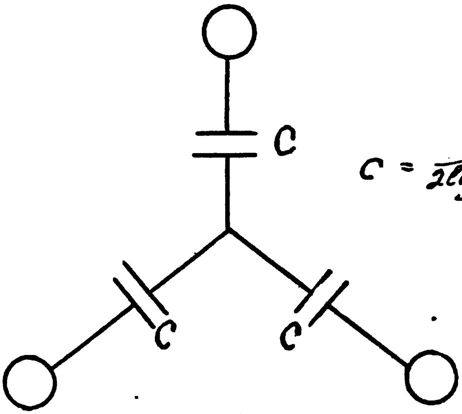
in micro-farads bet. one wire and neutral point for L miles of circuit.

$$\text{Charg. cur. per wire} = \frac{E \times C \times 2\pi \times f}{\sqrt{3} \times 10^6}$$

d = distance bet. wires, (inch).
r = radius of wire (inch).
L = length of circuit in miles.
E = E.M.F. bet. wires.
f = cycles per sec.
C = cap. in M.F. bet. one wire and neutral pt.

Charg. cur. three-phase $= \frac{2}{\sqrt{3}}$ (= 15.5%) × charg. cur. sing. phase for same d, r, L, and E.

If the wires are arranged on a straight line and not transposed, the line of zero potential moves harmonically between the two points midway between the two outside wires. The capacities between any two of the wires may be found by the method given, the unit quantity being moved from the surface of one wire to the surface of the other. If the wires are transposed, the capacity of the line may be approximately determined by adding the capacities of the several sections. The capacity for any arrangement will not differ greatly from that given for the wires arranged as in Fig. 5. Table 4 has been prepared for convenience; the capacity in microfarads and the charging current per mile with 10,000 volts between wires are given for a frequency of 60 P. P. S.



$C = \frac{1}{2 \log_e (\frac{d}{r})}$

FIG. 5.

The self-induction of the line experimented upon was determined by short-circuiting the line at one end and measuring the current produced by a known potential. The observed result agreed with the calculated value.

The self-induction of one wire of a three-phase circuit arranged on the corners of an equilateral triangle is usually calculated by assuming the other two wires as a return at a distance D. To get the inductive drop between two wires, the self-inductions are combined geometrically. This is correct, but as no mathematical proof has come to our notice, one is here given:

The wires are arranged as in Fig. 4, the currents in A, B and C being $I \sin \omega t$, $I \sin (\omega t - 120°)$ and $I \sin (\omega t - 240°)$

respectively. The number of lines of force threading A B per unit length of line at time t is

$$N_{ab} = 2I \sin \omega t \log \left(\frac{d}{r}\right) + \frac{I \sin \omega t}{2} - \left[2\, I \sin(\omega t - 120^\circ) \log \left(\frac{d}{r}\right) + \frac{I \sin(\omega t - 120^\circ)}{2}\right]$$

(Wire C has no effect on looop A B.)

$$= 2\sqrt{3}\left[\log\left(\frac{d}{r}\right) + \frac{1}{4}\right] I \sin\left(\omega t + \tan^{-1}\frac{1}{\sqrt{3}}\right);$$

giving for the self-induction of A B for length of line L

$$L_{ab} = 2\sqrt{3}\left[\log\left(\frac{d}{r}\right) + \frac{1}{4}\right] \times L. \qquad (7)$$

Table 5 gives values for L_{ab} for one mile of circuit for 66 P. P. S.

The self-induction of one wire considering the return at a distance d is

$$L_a = 2\left[\log\left(\frac{d}{r}\right) + \frac{1}{4}\right] \qquad (8)$$

Equation (7) may be obtained from (8) by combining L_a and L_b geometrically.

If the wires forming the circuit are arranged in a straight line and transposed, each wire taking the center pin for ⅓ the distance, wire C will have no effect on the loop A B. Arranged in this way the wires A B will be apart distanced d for two-thirds of the length of the line and $2d$ for the remaining one-third. The self-induction of the loop A B is, then:

$$L_{ab} = 2\sqrt{3}\left\{\left[\log\left(\frac{d}{r}\right) + \frac{1}{4}\right]\frac{2}{3}L + \left[\log\left(\frac{2d}{r}\right) + \frac{1}{4}\right]\frac{L}{3}\right\} \qquad (9)$$

This shows that aside from the question of transposing there is some advantage in arranging the wires on the corners of an equilateral triangle.

TABLE V.

Inductance per mile of circuit for three-phase system. 60 P. P. S.

Size B. & S.	Diam. in inch.	Distance d in inch.	Self. Ind. L_{ab} Henrys.	Inductance $L_{ab} \times 2\pi \times 60$ Ohms.	Size B. & S.	Diam. in inch.	Distance d in inch.	Self. Ind. L_{ab} Henrys.	Inductance. $L_{ab} \times 2\pi \times 60$ Ohms.
0000	.46	12	.00234	0.884	4	.204	12	.00280	1.057
		18	.00256	.967			18	.00300	1.133
		24	.00270	1.015			24	.00315	1.189
		48	.00312	1.178			48	.00358	1.351
000	.41	12	.00241	.910	5	.182	12	.00286	1.080
		18	.00262	.989			18	.00307	1.159
		24	.00277	1.046			24	.00323	1.220
		48	.00318	1.201			48	.00356	1.344
00	.365	12	.00248	.937	6	.162	12	.00291	1.098
		18	.00269	1.016			18	.00313	1.182
		24	.00285	1.076			24	.00329	1.243
		48	.00330	1.246			48	.00369	1.393
0	.325	12	.00254	.959	7	.144	12	.00298	1.125
		18	.00276	1.042			18	.00310	1.204
		24	.00293	1.106			24	.00336	1.269
		48	.00331	1.250			48	.00377	1.423
1	.289	12	.00260	.983	8	.128	12	.00303	1.144
		18	.00281	1.061			18	.00325	1.227
		24	.00308	1.125			24	.00341	1.288
		48	.00338	1.276			48	.00384	1.450
2	.258	12	.00267	1.008	9	.114	12	.00310	1.171
		18	.00288	1.088			18	.00332	1.253
		24	.00304	1.148			24	.00348	1.314
		48	.00344	1.299			48	.00389	1.469
3	.229	12	.00274	1.035	10	.102	12	.00318	1.201
		18	.00294	1.110			18	.00340	1.274
		24	.00310	1.171			24	.00355	1.340
		48	.00351	1.335			48	.00396	1.495

Basis of Table.

$$L_{ab} = 2\sqrt{3}\left[\frac{\log\left(\frac{d}{r}\right)}{0.434} + \frac{1}{4}\right]$$ = self ind. in C. G. S. units for loop *a. b.* (pec. cm.)

$$L_{ab} = 0.000558\left[2.303 \log_{10}\left(\frac{d}{r}\right) + .25\right] L, \text{ in henrys.}$$

Inductive drop in loop $ab = L_{ab} \times 2\pi \times f \times I$.

d = dis. bet. wires (inch).
r = rad. of wire, "
L = length of circuit in miles.
f = cycles per sec.
I = current in one wire.
For self ind. of one wire divide L_{ab} by $\sqrt{3}$

REGULATION OF TRANSMISSION LINES.

The question of the regulation of the system for possible power factors is important. Knowing the probable power factor of the load the line-drop may be calculated, thus determining the amount of regulation which must be allowed. If there are several sub-stations at different distances from the generating station to be supplied, the regulation to be allowed in each sub-station should be calculated. As the charging current of the line has an important bearing on the regulation of the system this question will be discussed.

At the present time there are two methods for determining the effect of the capacity current of a line on the voltage of the receiver. In the method most commonly used[1] the line capacity is assumed to be concentrated at one point, or for longer lines, the capacity is divided into several parts and these several capacities are connected across the line at various points. The pressures consumed over the line are then added geometrically to the receiver pressure. In the second method—involving hyperbolic functions—the algebraic results are worked out for distributed capacity. Both these methods are open to objection:

The first because for long lines—75 to 150 miles—it is quite laborious. The second method, while it is accurate and would be the only method to use if our transmission lines were several hundred miles in length, has the disadvantage that the equations come out in such form as to be practically meaningless to any but trained mathematicians. Most men do not like to use formulæ blindly: that is, formulæ which cannot be analyzed and each term given some physical meaning are not popular with practical men.

The method here given is a modification of the first mentioned, and will be found to give results, for distances up to 200 miles and possibly 300, as accurate as we could get by actual measurements on the completed line with the best instruments at present available for measuring alternating currents. Only one assumption is made that is not absolutely correct: The charging current per unit length of line is the same at all points of the line.

The error involved in this assumption can be very easily determined. The rise in voltage—with receiver circuit open—over a transmission line about 60 miles in length, and about 30″ between wires, is about one per cent. at 60 P. P. S.; the percentage rise being practically independent of the voltage applied to the line. The percentage rise in voltage varies, as will be shown, practically as the square of the length of the line and the square

---

[1] See "Alternating Current Phenomena," by C. P. Steinmetz, p. 158.

of the frequency. For the same frequency there will be a rise of about 4% over a line 120 miles long. This means, of course, that the charging current per unit length of line will be 4% greater at the receiver than at the generator. The percentage rise in voltage if this extra current be taken into account will be *less than*

$$\varepsilon < 4\% \, (1 + .04) < 4.16\%$$

That is, the error made is less than .16 of one per cent. of the line pressure. The error will reach one per cent. when the transmission line has a length of about 200 miles.

Aside from the above the regulation of step-up and step-down transformers and generator enter the calculations for the regulation of the system, and since the self-induction of these is usually several times larger than the line of self-induction and is known only approximately—especially the generator self-induction—it is needless to strive for great accuracy in the line calculations.

From the above considerations it will be evident that for an open-circuited line the charging current may be considered the same at all points of the line.

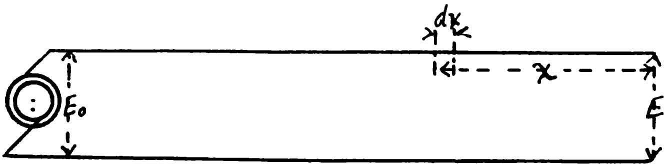


FIG. 6.

In Fig. 6. let

r = resistance per unit length of line.
l = self-induction per unit length of line.
c = capacity " " "
i = charging current " " ".
E_0 = E. M. F. at terminals of generator.
E = receiver E. M. F.
ω = frequency.
L = Total length of line.

The charging current crossing the element of line $d\,x$ at distance x from the receiver is

$$i_x = -Ej \; c\,x\,\omega$$

($-j$ is an operator to show that the current is 90° in advance of the pressure.)

The E. M. F. $d\,e$ consumed by the element of line $d\,x$ is (receiver open-circuited)

$$d\,e = -j\,E\,c\,\omega\,x(r - j\,l\,\omega)\,d\,x \tag{10}$$

Integrating this between the proper limits we get

$$e = -j\,\frac{i\,x^2}{2}(r - j\,l\,\omega)$$

$$= -j\,\frac{i\,x}{2}(r\,x - j\,l\,x\,\omega)$$

$$= -j\,\frac{I_c}{2}(R - j\,L\,\omega) \tag{11}$$

In the last equation, I_c is the charging current, L is the self-induction, and R is the resistance of the total length of line.

From equation (11) we see that if the charging current were the same for each unit length of line it would be mathematically correct to assume the line capacity concentrated at the center of the line, that is, at the center of gravity of the capacity load.

The percentage rise of potential will be practically equal to

$$e = \frac{C\,\omega\,L\,\omega\,100}{2},$$

in which C is the total capacity of the line. C and L are proportional to the length of line, and hence, the percentage rise in potential varies practically as the square of the length of line and the square of the frequency.

From equation (11) we get for the generator pressure

$$E_0 = E + e = E - j\,\frac{I_c}{2}(R - j\,L\,\omega) \tag{12}$$

As has been shown, I_c may be calculated by the equation

$$I_c = E\,C\,\omega$$

$$I_c = E_0\,C\,\omega$$

without appreciable error in the result of the percentage rise in pressure.

Graphically, equation (12) is as represented in Fig. 7.

$o\,a = E$ receiver.

$a\dot{b} = -j\,\frac{I_c\,R}{2}$.

$b\,c = \frac{-\,I_c\,L\,\omega}{2}$.

$o\,c = E_0$ at terminals of generator.

Suppose, now, we consider the receiver circuit loaded, and calculate the error made by assuming the charging current the same at all points of the line. Let the generator pressure be p per cent. higher than the receiver pressure, that is,

$$E_o = E\left(1 + \frac{p}{100}\right)$$

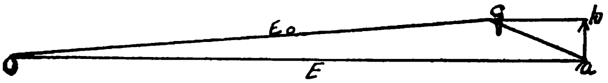


FIG. 7.

and assume that the potential along the line falls on a straight line from generator to receiver. (The true error will be less than that calculated with this assumption, since the pressure falls more rapidly at the generator than at the receiver.)

The charging current per unit length of line at a distance x from the receiver circuit will be

$$i_x = i\left(1 + \frac{p\,x}{L\,100}\right)x.$$

(L is the total length of line; i is the charging current at receiver circuit.)

Suppose the angle of lag of the receiver load to be θ, then, the total load current may be written

$$I = I\cos\theta + j\,I\sin\theta.$$

The current crossing the element of line $d\,x$ is

$$I_t = I\cos\theta + j\,I\sin\theta - j\,i\left(1 + \frac{p\,x}{L\,100}\right)x.$$

The E. M. F. consumed by the element of line $d\,x$ is

$$d\,e = \left[I \cos\theta + j\,I \sin\theta - j\,i\left(1 + \frac{p\,x}{L\,100}\right) x \right](r - j\,l\,\omega)\,dx.$$

Integrating, we get for the E. M. F. consumed over the line

$$e = I\cos\theta\,(R - j\,L\,\omega) + j\,I\sin\theta\,(R - j\,L\,\omega) -$$

$$j\,\frac{I_c}{2}\left(1 + \frac{p}{3\times 100}\right)(R - j\,L\,\omega) \qquad (13)$$

The percentage rise due to charging current will be *less than*

$$\varepsilon = \frac{C\,\omega}{2}\left(1 + \frac{p}{3\times 100}\right) L\,\omega\,100.$$

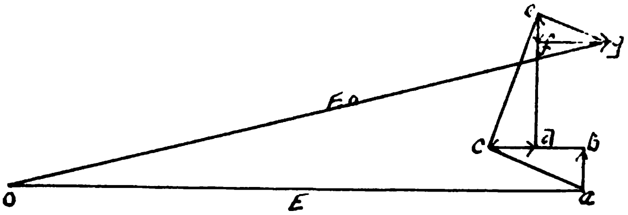


FIG. 8.

If we take $C\,\omega \times \frac{L\,\omega}{2} \times 100 = 4$, that is, a line about 120 miles in length, and give to p a value as high as 20—the generator pressure is 20% higher than the receiver pressure—we get

$$\varepsilon = 4\%\left(1 + \frac{20}{300}\right) = 4\%(1 + .06) = 4.24\%.$$

The error made by assuming charging current constant is about one-fourth per cent. of the line pressure.

It is evident, then, that either for a loaded or unloaded line the charging current may be considered constant. Equation (13) may therefore be written

$$e = I\cos\theta\,(R - j\,L\,\omega) + j\,I\sin\theta\,(R - j\,L\,\omega) - j\,\frac{I_c}{2}\,(R - j\,L\,\omega).$$

The pressure at generator terminals is

$$E_0 = E + e$$

$$= E + I\cos\theta\,(R - j\,L\,\omega) + j\,I\sin\theta\,(R - j\,L\,\omega) - j\,\frac{I_c}{2}\,(R - j\,L\,\omega).$$

This equation is represented graphically in Fig. 8.

$$ab = -j\,\frac{I_c\,R}{2}.$$

$$b\,c = -\frac{I_c\,L\,\omega}{2}.$$

$$c\,d = +I\cos\theta\,R.$$

$$d\,e = -j\,I\cos\theta\,L\,\omega.$$

$$e\,f = +j\,I\,R\sin\theta.$$

$$f\,g = +I\,L\,\omega\sin\theta.$$

Instead of combining the currents geometrically as we proceed from receiver to generator we see that we may consider each component of the receiver current as flowing over the entire line impedance, and the capacity current as flowing over the impedance from the center of the line to the generator. Looking at the matter from this point of view the E. M. F. at the terminals of the generator, or the total E. M. F. generated, may be at once written out for any line.

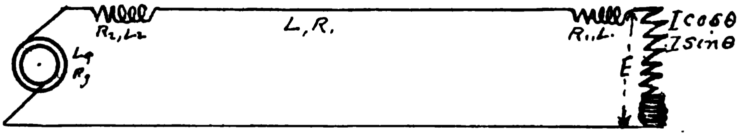


FIG. 9.

Let in Fig. 9.

R_1 = equivalent resistance of step-down transformers.[1]

R_2 = “ “ “ step-up transformers.

L_1 = “ self-induction of step-down.

L_2 = “ “ “ step-up.

$R\,g$ = “ resistance of generator.

$L\,g$ = “ self-induction of generator.

R = resistance of line.

L = self-induction of line.

---

[1] It is customary to convert all pressures to equivalent full-line pressure. If r_1 is the resistance of primary transformer and r_2 the resistance of the secondary, the equivalent resistance R_1 is calculated by the formula

$$R_1 = r_1 + r_2\,n^2,\ n \text{ being the ratio of transformation.}$$

The equivalent self-induction of transformers is determined from the ohmic pressure-drop and the short-circuited regulation.

Also let

$$L_t = L_1 + L_2 + L_g + L.$$
$$R_t = R_1 + R_2 + R_g + R.$$

The E. M. F. generated is

$$E_g = E + I \cos\theta\,(R_t - j\,L_t\,\omega) + j\,I \sin\theta\,(R_t - j\,L_t\,\omega) -$$
$$j\,I_c\left(\frac{R}{2} + R_2 + R_g\right) - j\left(\frac{L}{2} + L_2 + L_g\right) \qquad (14)$$

The figure representing this will be similar to Fig. 8. Each component current is represented by the pressure triangle corresponding to the impedance over which that current flows. That is, each component current may be considered as producing the same effect as though no other current flowed over the line. The advantage of this way of looking at the matter is that we see by a glance at the equation or the figure how a change in any component current will affect the pressure relations of receiver and generator. To illustrate this, let us assume the load to remain constant and determine how the generator pressure must vary to give constant receiver pressure for any change in power factor of the load.

The charging current remains constant; therefore, the triangle A B C, Fig. 8, does not change in magnitude or position. Since the load is assumed constant, the value $I \cos\theta$ is constant and, consequently, the triangle C D E does not change. The only variables are I and $\sin\theta$. We have, however,

$$E\,I \cos\theta = W \text{ (a constant)}$$

$$I = \frac{W}{E \cos\theta}$$

and

$$I \sin\theta = \frac{W \tan\theta}{E}.$$

The triangle E F G always remains similar to triangle C D E. The point g, therefore, moves on the straight line $e\,g$ (if the load current is leading, $e\,g$ must be drawn in the opposite direction) for variable power factor. The length $e\,g$ increases directly as $\tan\theta$ and is drawn at right angles to $c\,e$.

Equation (14) may be solved for E_g algebraically most easily by writing

$$E_g = \left[E + I\cos\theta\,R_t + I\sin\theta\,L_t\,\omega - I_c\left(\frac{L}{2} + L_2 + L_g\right)\omega\right]$$

$$-j\left[I\cos\theta\,L_t\,\omega - I\sin\theta\,R_t + I_c\left(\frac{L}{2} + L_2 + L_g\right)\omega\right]$$

and adding the terms in the square brackets before taking the square root of the sum of the squares. Laid out on paper to a large scale it will be found that results sufficiently accurate for most practical purposes can be obtained with a small amount of labor. Another advantage of the graphical method is that it presents to the eye a picture of the entire circuit.

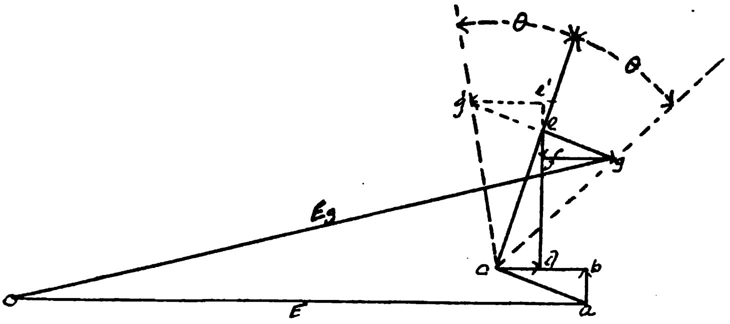


FIG. 10.

The method of finding the regulation for variable load and constant power factor is shown in Fig. 10.

The magnitude of $c\,e$ is proportional to I, that is, proportional to the load for constant power factor, since

$$c\,e = I\cos\theta\,(R_t - j\,L_t\,\omega);$$

the magnitude of $e\,g$ is proportional to the load also, since

$$e\,g = j\,\frac{W}{E}\tan\theta\,(R_t - j\,L_t\,\omega).$$

$e\,g$ is always drawn at right angles to $c\,e$. The triangles $c\,d\,e$ and $e\,f\,g$ are always similar and for constant power factor increase in the same ratio. While the point e moves along $c\,e$, the point g moves along $c\,g$, the line $c\,g$ making an angle θ with $c\,e$. If the current leads by the angle θ the locus of g will be along the $c\,g.'$

In Fig. 11 the arc of a circle has been drawn with 0 as center and o c as radius. If the receiver pressure is to remain constant with constant generator pressure, the locus of g must be on the arc of this circle.

If there is an inductive receiver load the regulation will be very unsatisfactory unless $f\,g$, Fig. 10, decreases more rapidly than $c\,d$ increases. $c\,d$ increases with the load, $f\,g$ increases or decreases as

$$\frac{W}{E}\tan\theta$$

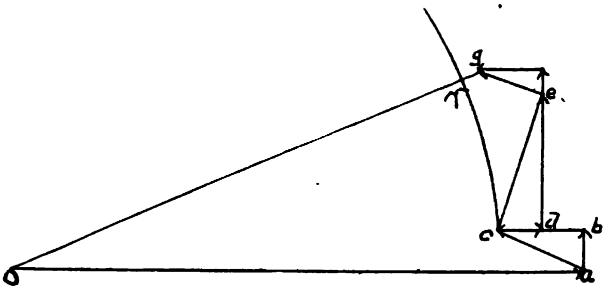


Fig. 11.

increases or decreases. On an induction motor, as the load increases the lag decreases, therefore, a load of this kind after starting does not interfere very much with good regulation. The regulation of the receiver for constant pressure is most difficult when we have a synchronous motor which is carrying a variable load, such as a street railway load.

It is seen from Fig. 11 that in order to keep the receiver pressure constant the leading component of current $I\sin\theta$ must increase as the load increases or θ must change from lag to lead. This can, of course, be done when a synchronous motor is running a street railway generator by putting a shunt and series winding on the field of the motor. For the sake of economy θ is usually changed from lag to lead as the load increases by under-exciting the motor for loads below the average load, and over-exciting for loads above the average. In Fig. 12 suppose

$$I \cos \theta \, (R_t - j \, L_t \, \omega),$$

which is proportional to the power intake of the motor, is represented by the triangle *c e* at full load, by *c e′* at average load and by *c e″* at no load. With *o e′* as radius draw with 0 as center the arc of a circle through *e′*. Then at full load the motor must be over-excited so that the length

$$e \, g = I \sin \theta \, (R_t - j \, L_t \, \omega)$$

will reach the circle. Similarly at no load the motor must be under-excited so that *e″ g″* will reach the circle.

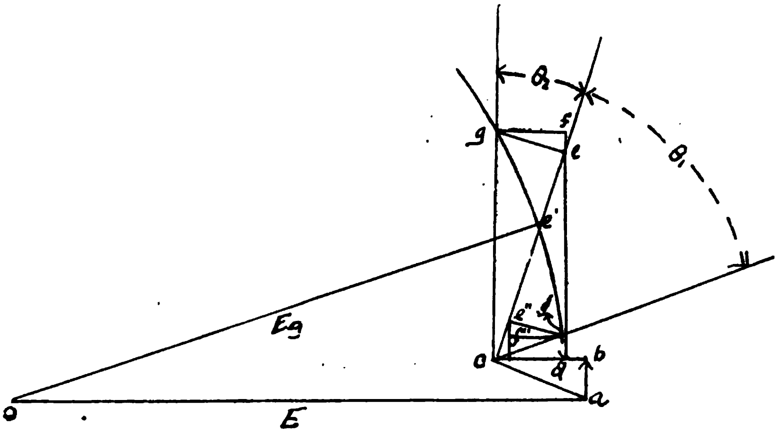


FIG. 12.

By laying off the pressures to a large scale the angles θ_1 and θ_2, Fig. 12, by which the current must lag and lead at no-load and full-load respectively, may be very closely determined. From the constants of the motor it will be possible by the aid of the synchronous motor diagram to determine the excitation for no-load and full-load to give constamt receiver-pressure with constant generator-pressure. The motor may then be run as a generator and the no-load excitation set to the value determined. The current in the series field coil corresponding to full-load on the motor could next be adjusted by the series field shunt until the pressure developed by the motor as a generator corresponded to the full-load excitation as found above. The motor would then carry its load without causing much variation in the receiver-pressure. It is necessary to know only the no-load power of the motor and the self-induction and resistance of the entire circuit including that of the generator and motor.

SOME TRANSMISSION LINE TROUBLES.

At the end of the two-phase forty-mile transmission line there were in operation two shunt-wound synchronous motors, 100 K.W. and 50 K.W., running street railway generators. It was found that these motors behaved very badly at no-load and not all satisfactory at all loads.

At no-load the motors would take almost full-load current and were very unstable, falling out of synchronism for a sudden small increase of load. At about full-load the current would be but little above what it ought to be and the motors became more stable. Changing the excitation of the motors did not improve their action. The following readings taken on the 100 K. W. motor at no-load may be of interest.

(Instruments in one-phase.)

I	E	$Wa = IE$	W	Cos θ	θ	Excitation
18.2	111.5	20.2	10	0.49	60°	For min. cur.
18.4	113.5	20.9	10.4	0.49	60°	" "
19.3	110.9	21.4	9	0.42	65°	" "
18.8	115	21.6	10.2	0.47	62°	" "
30	119	35.7	8	0.225	77°	For min. watts.
20.8	116.5	24.2	11.2	0,47	62°	" "

The measurements were made with Weston instruments that had been checked; the readings were taken on one phase and then on the other. The motors operated across a 2200-volt-line; the value of E obtained by use of 20 to 1 multiplier. The full-load current should be about 22 amperes.

The 50-K. W. motor acted in a similar manner; the no-load current was 14 amperes. A water rheostat was connected in each phase of the 50-K. W. motor; with 8 ohms added the no-load current was 12.2 amperes. The motor at this point dropped out of synchronism on adding a small length of shafting.

There was no "hunting" of the motors. Copper bridges were put in between the poles of one motor, but this did not improve its action. Since there was no hunting, the failure of the bridges to improve the action of the motor was predicted. The large no-load current was believed to be due to the difference of wave shape between generator and motor E. M. F's, the motors acting during part of a cycle as motors, and during the remainder as generators, sending energy back to the system. This explanation seemed to be the only possible one. The difference in wave shape of generator was believed to be due to the magnetizing action of the capacity current distorting the wave shape of the generators. As is well known, the effect of a capacity current is to flatten the E. M. F. wave, and may in an extreme case produce a "jagged" wave.

That the above explanation is the correct one was satisfactorily proved by taking off at the receiver-end of the line a lagging current to neutralize the capacity current. The secondary windings of two transformers were used as induction coils, the magnetic circuit of the transformers having been opened to increase the lag angle.

With the capacity current nearly neutralized it was found that the 100-K. W. motor when running a piece of shafting took 11.5 amperes. The induction coils were then taken out and the motor current increased to 23 amperes, and could not be reduced by changing the excitation. The 50-K. W. motor drew 13 amperes per phase at no-load with the induction coils out and 3 amperes with the coils in. With the coils neutralizing the capacity current the synchronous motors would not fall out of synchronism.

The variation in voltage at the receiver station was about 10% when the synchronous motors were running the railroad without the induction coils, and about 3% under the same conditions as to load but with the induction coils taking enough current to neutralize the capacity current. This 3% variation of receiver voltage was nearly all due to the change of speed of the waterwheels.

DISCUSSION.

THE PRESIDENT—Gentlemen, the paper is now open for discussion.

MR. STEINMETZ:—Mr. President, with your permission I desire to say a few words regarding this extremely interesting paper. I do not see any reason for using two letters when a single letter can be used. I would leave the Omega out and put in the Standard letter. But that is a minor matter.

DR. PERRINE:—It was done to show where the *l* came from which previously we had worked out.

MR. STEINMETZ:—This shows the capacity of the line; and something very important is the condition found in power transmission, but to a certain extent it is of secondary importance; that is to say, it is not so essential to calculate the extent of capacity accurately, but with approximation; and in most cases almost any approximation will do. What is necessary is rather to determine the limiting value of the effect of capacity, to see whether this effect is of sufficient amount to require a more accurate investigation; and as a rule we find it is not. Here in this very long transmission, while it is considerable, it is not of such importance as to require a very accurate determination of its effect. The only case of which I know where the capacity is of considerable magnitude is probably the transmission of my friend Mr. Nunn; and this is considered due to the very high voltage and the comparatively small amount of power; and my friend Mr. Nunn told me had obtained some valuable information.

There is one further remark I would like to make regarding the last experience referred to by the speaker, in these synchronous motors taking excessive current. Now it is quite possible that wave-shape had something to do with this, but I am not quite sure of that, for somehow or other, I do not really believe much in the wave shape. While wave-shapes are very important theoretically, I have never yet found any case where any difficulty could be traced to the wave-shape without any doubt —without permitting any other explanation. On the other hand, there are many cases where disturbances have been observed, and explanations made for it by the wave shape, but after being investigated they were found not to have anything to do with it. In one case of a converter the current increased out of all proportion as the load came on, and I found somebody made a very ingenious explanation of how that was due to the wave-shape; but I sent one of my assistants there, who did not believe in wave-shape, and after carefully looking over it he found the series field reversed, and so the armature had to magnetize the field. Now, in coming to this particular instance here, it may be the wave-shape, but I think there is possibly a different explanation, though I cannot say which is accurate, the real reason being that I am not sufficiently familiar with the conditions. If you take a transmission line equal in length to one-fourth of the wave—a one-fourth wave-length—and then impress a constant electromotive force at the generator end of the line, you will get at the receiving end a constant current. The transmission line has such capacity or induction as will be one-fourth of the wave. [Illustrating]. If the length is exactly this, whatever apparatus you put at the receiver end it will always take the same current. This is an extreme case, but even with a line very much shorter than that, as soon as the length of the line increases to a certain extent by the effect of the capacity and self-induction, there is such an effect at the receiving end as tends to regulate for constant current. A very frequent case, the shunting of an induction motor at the receiving end of the line, or a shunting of a self-induction coil, will throw the self-inductive capacity of the system sufficiently out of balance to spoil this tendency to constant current regulation. I do not know whether this is a condition existing here or what else the condition was. What I want to say is that from the data given here we are not entitled yet, I think, to conclude that the wave-shape had anything to do with the phenomenon, and I should rather believe that the wave-shape had nothing to do with it.

Dr. Perrine:—Before Mr. Steinmetz sits down—I confess I am very nearly as much a disbeliever in wave-shapes as Mr. Steinmetz is, but I have been faced by this problem. Starting with the generator unloaded, there was a motor current of 23 amperes. With a lagging current of 18 amperes at the receiver the motor current dropped to 11½ amperes; and Mr. Steinmetz cannot say that there is anything the matter with the motors, because they are his own motors.

Mr. Steinmetz:—The only suggestion I would make of that, is inserting self-induction.

Mr. Baum:—Mr. President, Mr. Steinmetz in his last remarks has given, in another way, our explanation; that is, instead of saying the excessive motor current was due to wave-shape, suppose we say it was due to "hunting" at 60 cycles per second. That means exactly the same thing. In our paper we say the motor during part of the cycle acted as a motor and during the remainder of the cycle as a generator. Does not that mean the same thing as saying that it was "hunting" (electrical hunting) at 60 cycles per second? In the motor we believed there was a triple frequency current, and on that assumption went to work to cure the trouble. The General Electric Co.'s engineer out there did not agree with us; like Mr. Steinmetz, he said it was "hunting." He wrote back to the main office and sent all our measurements; they sent back a report that it was "hunting," and sent out bridges to put in between the pole tips of the motor —the usual cure for "hunting." We predicted that the bridges would not cure the trouble. The fact is that the bridges had no effect whatever to reduce the motor current. Then to show that our explanation was the correct one we threw in the induction coils and the motor current immediately dropped, in one case one-half, and in the other from 14 to 3 amperes, and could then draw leading or lagging current by varying the excitation. Before that we could do nothing at all with the excitation to reduce the current taken by the motors.

DR. KENNELLY:—Mr. President and gentlemen. We started with a paper on aluminium, and aluminium is so light that we got into the airy fields of mathematics; and with your permission I beg to say a few words now about aluminium and the wire, because the task fell to my lot to make measurements of samples of the wire, and I examined about a hundred samples and made as careful tests as I could upon its electrical and mechanical properties. The electrical properties were very nearly uniform. There was very little difference between the electrical conductivity of any of the lots that I had occasion to examine, and this appeared to be due to the relatively high degree of purity of the wire and the absence of admixture or alloy. The fracture of the wire always assumes a characteristic form and terminates in a peculiar nipple at each side of the break. I think that if the wire were defective it would be more likely to break off flush. With steel wire there is a small, steady, elastic elongation until you get beyond a certain limit, and then the permanent elongation increases very rapidly; but in the case of aluminium wire, you cannot assign any particular point at which the elastic limit can be said to lie. All you can say is that the stress shall not exceed a value at which the elongation shall be appreciable; and from the statements that have been made to us in the paper, it seems that there is no difficulty in arriving at that point in practice.

DR. PERRINE:—We derived that from your curve

DR. KENNELLY:—In regard to the determination of the pressure at the receiving end of a line, if the capacity of the circuit is assumed as collected together into one condenser and located in the centre of the line, the assumption is quite good enough for most practical cases, namely, a case of low frequency on a line not greater than 200 miles in length, and with ordinary capacity and inductance of overhead copper conductor, but you may have cases of short wires with exaggerated capacity or inductance, and in cases of high frequency you will be unable to obtain sufficient accuracy; and in such cases I believe in the use of hyperbolic functions. I don't think there is any difficulty in using them after a few trials.

I want to make one humble protest against the use of what I think is an inversion, or what I will submit is an inversion of the direction of reactances, geometrically. I see the reactances in this paper are all written $r - jx$, and, as a mere matter of convention, I would submit that that is undesirable. It is not a question of what is right or wrong. If you accept the notation, it is all right. I have always maintained that the reactance of a reduction coil should be written $r+jx$. I have the honor to differ upon this point with Mr. Steinmetz, who, I think, is responsible—I am not sure, but I think he is responsible—for introducing negative reactance, and I think he justifies his position upon astronomical grounds. I am quite ready to sacrifice my view if it should be generally agreed that reactance should be measured negatively and a condenser measured positively, and with a lagging current which should be measured in that direction. But, in trigonometry, we always measure angles positively in the counter clockwise direction, and a negative lag angle should be in the negative direction. I think it would be a good plan to bring that matter up and have a consensus of opinion. Whenever I read Mr. Steinmetz's mathematics, I have to stand on my head in order to understand the reactances.

MR. STEINMETZ:—Having been challenged regarding these formulæ, I may give my reason for having adopted them. It is not based on astronomical reasoning. Astronomical reasons led me to adopt the counter-clockwise direction. The reason it happened to be minus in my case and plus in another, in the method of graphic representation, it is nothing but a symbolic method of graphical representation. Long before anybody thought of electrical engineering, polar co-ordinates were used, with the time as angle or amplitude, and the instantaneous value as vector. Now, somehow or other, when graphical representations were first introduced—they were introduced by Kapp, I think, and others—they seem not to have thought of the familiar system of polar ordinates, but discovered and invented a different method of representation. They chose a line representing the maximum value of the current, and they let that line rotate around, and a projection of this line represented the instantaneous value. It is a very interesting method, and it has been introduced to a certain extent; the only objection is, that a better representation has been known in the common polar co-ordinates since a few centuries. Here is the sketch of Dr. Kennelly. In his representation, this current is lagging behind the electromotive force, because if he takes his line and revolves it around it comes there later. But if you represent it, not by some artificial method but by the standard polar co-ordinate system, then we denote the electromotive force by the diameter of its polar circle. If the current is lagging, the maximum value of the current will be reached at a later time. So these signs depend upon the graphical method you choose in starting. You may use a polar system, which is used in all engineering branches, as, for instance, in giving the valve motion of steam engines, or you may choose some special method not used anywhere else.

THE PRESIDENT:—Is there any further discussion? Mr. Nunn, I believe, has had considerable experience with aluminium lines, and we shall be very glad to hear from him.

MR. PAUL N. NUNN.—The question of aluminium lines is one of a great deal of interest, I believe, to all who have long distances to reach, especially where the distances are such and the conditions such as to permit of the use of quite high pressure. I do not believe that I have anything to offer the INSTITUTE this morning upon the question under discussion. The questions involved are pretty complicated. I am not prepared to offer a word on the authentic evidence given this morning. I have found a great deal of difficulty in satisfying myself of just the conditions which would obtain upon the erection of long aluminnium lines, and while I suppose the information at hand, with most of us, is sufficient to determine pretty closely, within 1.5 per cent., I think that is near enough. We are interested in those practical results, but closer than that I think it is a question of scientific interest very largely, and a great many of us are not prepared to go into such a question to the extent necessary, simply on the ground of scientific interest. Our observations of the use of aluminium are very interesting, but I do not know that there is anything in it to throw a particle of light on the question as discussed here this morning. I may say that I think we are in a position to second the statement which has been made that the alloyed aluminium, or certain alloyed aluminium, is not safe. I do not think this should perhaps be expressed too generally. There is a line in very successful operation, I understand, and I cannot learn that there has been a particle of trouble from it, in which the alloy is very considerable, put in very carefully; but the common alloyed aluminium, which I believe instead of being alloy is impure aluminium, handled under the brand of XX and BB or something like that, is defective because it is not homogeneous. The INSTITUTE might be interested in knowing that in about six miles of a certain aluminium circuit which we erected something over a year ago, during the first month of its erection, I cannot say use, it broke, an average of every 100 feet in length, or every span. There were fifty-two breaks to a mile in a month. It took the services I believe of four men all the time to repair breaks. We simply let that go on, to see how long it would continue. We do not know; we finally stopped it. There were but four breaks in that six miles which showed an elongation of 2%—enough elongation so that the eye could distinguish it; and in several cases I noticed something which appeared like a physical defect, a sliver, along the side, which showed something in the way of drawing; it was rough; the appearance was somewhat crystalline, and apparently it had broken exactly as a piece of glass would break, that is, square. We photographed some of these ends and sent them to the Pittsburgh Reduction Company, and I think the trouble was understood the moment they saw the photographs. There was only one condition under which that could occur—the case of an ingot in which the impurity or alloy was not thoroughly mixed and did not produce a homogeneous mass. It seems to me as if in the process of drawing, that impurity settles in the form of an infinitely thin stratum through the wire and that under conditions of moderate stress, probably in our case seldom exceeding 1,500 pounds to the square inch, it is attended with vibratory results. We have replaced much of this line, practically all, with pure aluminium, stranded, and have not had a particle of trouble. I think the question of resistance in joints is one with which we must labor for some time to come. I have learned that aluminium deteriorates particularly in a country where it is subject to alkalies, or to what is termed corrosive salt. The series of joints, which were at first very promising, afterwards became quite troublesome.

DR. PERRINE:—I would like to reply to one or two of these points that have been made. In regard to the elastic limit that Dr. Kennelly describes; from the curve which he gave here to-day we determined the strain that it would be safe to allow, and it was found to be satisfactory. I examined a large number of the breaks from the lines that were giving the most trouble, and found that in every case they were exactly as Mr. Nunn described them. The break is a shear, a sharp break, with a reduction of area on one side simply, which is the characteristic break of imperfectly alloyed wire. I have had a good deal of experience with imperfectly alloyed wire while trying to make silicon bronze, and the breaks were of that character; and almost all imperfectly mixed alloys will give that sharp break without any reduction in area. There is apparently a break from the wire falling, and getting a slight reduction of area on the under side and then shearing square across; it is not a break that is characteristic of aluminium any more than it is of any other imperfectly alloyed material. I take that characteristic of the break as one reason for saying these are imperfect alloys; and the other reason mentioned in the paper is that one of the lines which we had an opportunity to test gave trouble on one-half of the line and the other half gave no trouble at all. There were three breaks in one-half of the line due to short-circuit, or something falling across the line; and in the other half of the line there were 30 breaks a month, and that over its entire length, although it was said to be the same sort of wire The resistance of the whole line showed the wire to have only 90 per cent. electrical conductivity. This could not be due to hard drawing. By hard drawing you might get one or two per cent. resistance increase, but 10 per cent. increase must necessarily mean an alloy. The peculiarity of the elastic limit is not different from the peculiarity of the elastic limit of metals in the same group as aluminium, and in that respect copper groups with aluminium. In hard-drawn copper we have such a small percentage of elongation before breaking, but I have never yet seen any one who was able to draw the curve for the elongation of copper; but when we break soft-drawn copper we find it proceeds almost exactly as the aluminium was found to elongate in this case. It is a general idea with many metallurgists that hard drawing does not change the relative position of the elastic limit. As regards these points there seems to be nothing new that aluminium has introduced into the art of metal working. It is simply that, being a metal that is liable to irregularities, it must not be used unless it is carefully inspected. I attribute our success in this line more to the careful inspection which Dr. Kennelly gave to the metal before we put it up than any other thing.

As regards the question of the signs of the complex quantities I thoroughly agree with Mr. Steinmetz. I studied complex quantities long before I studied alternating or direct currents. After I had studied complex quantities I began to study rectangular coordinates. The angle of lag seemed to me to be always the other way. It seems to me the system which Mr. Steinmetz developed is a rational system, and the only unfortunate thing is the man who has reached one system does not dare to touch a paper written by the man who has written in the other system.

The Secretary:—There will be a collation served in this building at about one o'clock, and after that the remaining papers will be taken up. Professor Rowland will be very happy to have the members, after the collation or at any time, look about this building. It is very interesting. He has circulars describing the various courses given at the Institute, which may be had at the Secretary's office in the lobby.

Mr. Dunn:—Mr. President, our Secretary's announcement of the collation reminds us of the very many courtesies that have been extended to us by the Reception Committee and by our brethren in Philadelphia, and if hospitality is one of the cardinal virtues it is certainly proper to acknowledge it. I am not sure but that in the motive of my remarks there is something in the nature of the expression by an old cynic, that gratitude is a desire for future favors. But be that as it may, I am sure that our experience here in Philadelphia has been so pleasant that we all desire such future favors and hope it will be soon when we shall again come here. I would therefore move that a committee be appointed by the Chair to draw up suitable resolutions acknowledging these courtesies and hospitalities which have been extended to us, and expressing in corporate action the same acknowledgment and thanks which have already been made by us individually. I am sure in speaking in this way I am voicing the sentiment of every member of the Institute who has attended this general meeting.

The resolution was carried and the President appointed as such committee, Calvin W. Rice, George F. Sever, and W. W. Ker.

The President:—The next paper is entitled: "A Practical Transmitter using the Sine Wave for Cable Telegraphy; and Measurements with Alternating Currents upon an Atlantic Cable," by Dr. A. C. Crehore and Capt. G. O. Squier.

A paper presented at the 17th General Meeting of the American Institute of Electrical Engineers, Philadelphia, May 18th, 1900. President Hering in the Chair.

A PRACTICAL TRANSMITTER USING THE SINE WAVE FOR CABLE TELEGRAPHY; AND MEASUREMENTS WITH ALTERNATING CURRENTS UPON AN ATLANTIC CABLE.

BY ALBERT C. CREHORE, PH. D. AND GEORGE O. SQUIER, PH. D.

This paper describes a method of utilizing the sine wave of electromotive force for cable signaling, and a practical cable transmitter employing these principles. The employment of a sine wave electromotive force makes available the ordinary methods of measurement such as are used on power transmission lines, and some results are given of such measurements upon submarine cables.

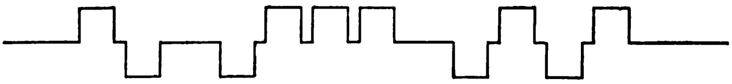


FIG. 1.—Letters A, B and C. Battery form of electromotive force wave.

The present method of operating long cables employs a primary battery as the source of power, and a siphon recorder to record the signals. In this system a dot is transmitted by a positive current obtained by connecting one pole of the battery to the cable and the other to the earth, and a dash by a negative current connecting the opposite pole to the cable, the time required for a dot and a dash being the same.

Several letters of the alphabet require two or more consecutive signals in the same direction, and in order to separate these successive signals at the receiver it is usual to connect the cable to earth during the latter portion of each individual signal. The electromotive force employed in transmitting the letters A, B and C, is shown in Fig. 1, where it is seen that the cable is directly connected to earth during one-fourth of each signal. This represents the form of electromotive force as furnished by the battery and transmitter, and if no condensers were used would be the form of wave applied to the cable; but it is usual to employ condensers at each end of the cable whether working simplex or duplex, and these condensers greatly modify the shape of the electromotive force which is applied to the cable itself as will be shown later.

It is important in designing a sine wave transmitter to make an instrument which transmits to the cable the same combinations of impulses as those at present employed in cable signaling, so that as far as the receiving station is concerned there is no change whatever required either in instruments or technical staff. The difference between the ordinary and the sine wave method is in the shape of the electromotive force employed for each individual signal at the transmitting end of the cable. In the sine wave system instead of the square topped form shown in Fig. 1 each signal consists of a single sinus or semi-wave of alternating current, as represented in Fig. 2.

FIG. 2.—Letters A, B and C. Sine wave electromotive force.

The diagram Fig. 3 represents a method of producing the required combinations of signals by means of a dynamo alternator. The armature rotates continously, and a wheel, W, geared to the alternator shaft feeds the paper tape, T, in synchronism with the electromotive force generated, so that one semi-wave of electromotive force is generated during the time that the tape is advancing a distance equal to the distance between the centers of two consecutive feed holes. The transmitting tape is similar to the ordinary tape, having a row of perforations on one side of the feed holes to transmit dots, and on the other side for dashes. Brushes are employed for making contact through these perforations, and by making the holes a proper size the duration of contact can be made equal to the whole or any portion of the semicycle desired. The two brushes for transmitting the signals are on the same line transversely across the tape, and each brush is connected to one terminal of the armature winding through a divided ring, A, which causes pulsations of electromotive force to be supplied to the transmitter brushes P and Q consisting of successive semi-sinuses in the same direction A continuous ring, B, is also supplied which connects the middle of the armature winding to line. The contact S upon which the

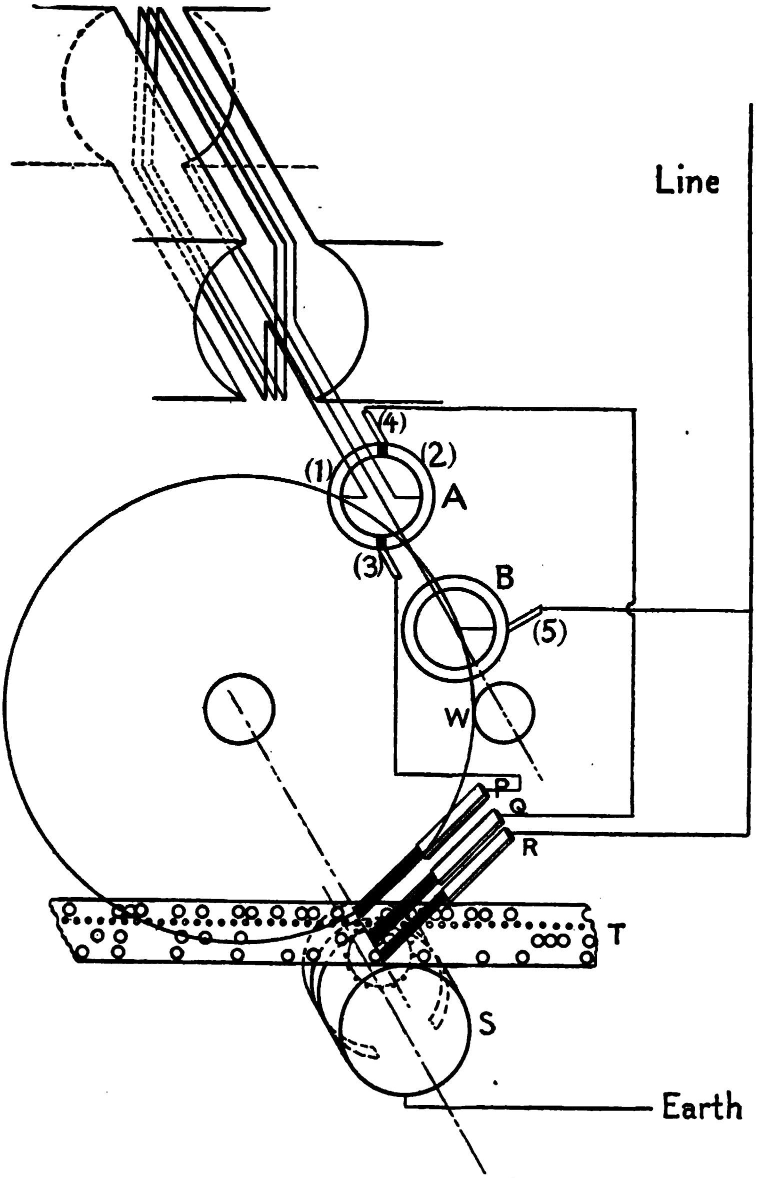


FIG. 8.—Diagram of cable alternator and transmitter.

three brushes P, Q, and R bear is connected to the earth or return. Thus it appears that whenever contact is established on the dot side of the tape between P and S a positive sinus is transmitted to line, and contact between Q and S on the dash side sends a negative sinus.

The arrangement just described transmits the proper combinations of signals, but does not provide for discharging the cable between letters and words; for without the brush R the two brushes P and Q would completely insulate the line from the earth at the ends of letters and words. This earth connection is provided between letters and words by adding to the tape a third row of holes and supplying the third brush R which connects the line directly to earth whenever a perforation occurs. A sample of the transmitting tape is shown in Fig. 4, where the letters A, B and C are represented. Evidently to send a simple alternating current to line with this transmitter it is only necessary to perforate dots and dashes successively, but the brushes must be so placed that contact through the perforations shall take place at the instants when the current is approximately zero, as will be more fully explained later; otherwise there will be a disturbance which distorts the form of wave from its true sine form.

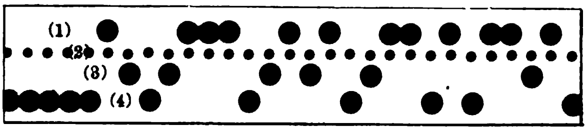


FIG. 4.—Sample of transmitting tape, showing letters A, B, C, D, E and F. (1) is the dot row, (2) the feeding row, (3) the dash row and (4) the space row for earthing the cable between letters and words.

To adjust the brushes easily they are mounted upon the same carriage which is adjustable along the tape by means of a micrometer screw. This adjustment may be made by receiving the current from an alternating tape on a local siphon recorder which will record a smooth sine wave when the brushes are in proper adjustment. This setting should be made when using the actual cable, not with a local circuit, since the phase of the current is different on different circuits, according to their electrical properties.

The three-hole tape is prepared on a perforator which differs from the ordinary form only in the arrangement of the punches.

The operator can detect no difference between its action and that of the ordinary perforator. With a slight change the ordinary perforator can be adapted so as to prepare the three-hole tape.

One peculiarity met in designing a dynamo alternator for working long cables is the low frequency required, which for an Atlantic cable is as low as three or four per second, while the ordinary frequencies of alternators for lighting and power circuits vary from 25 to 150 per second. A means of increasing the frequency is to increase the number of poles of the machine, but if the object is to decrease the frequency in this way the number of poles cannot be less than two. One revolution of an armature in a two pole field gives a complete cycle of electromotive force which limits the speed of the armature to three or four revolutions per second.

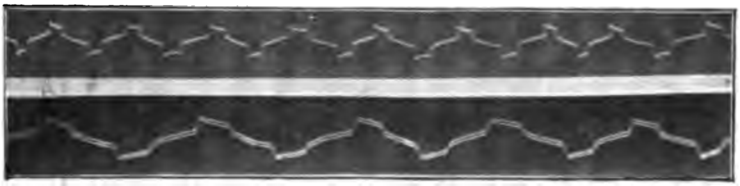


FIG. 5.—Oscillograph record of alternating electromotive force obtained from a shuttle wound armature in a two-pole field.

In the armatures designed, the reactance even at these low frequencies rather than the resistance, is the controlling factor in determining the short-circuit current, and is so great that the armatures may be short-circuited at any time. The inductance of the whole armature is four times that of the half armature, as the two halves are identical, and the mutual induction between the halves is equal to the self-induction of one half. Since the electromotive force generated by the whole armature is twice that of the half armature, it results that the short-circuit current of the whole armature is only half that of the half armature.

An armature was constructed shuttle wound and gave a form of wave differing greatly from the sine wave, the electromotive force being shown in Fig. 5 as determined photographically by an oscillograph. Drum-wound armatures were made which give very accurate sine waves as shown by oscillograph records. As will be presently explained, experiment showed a superiority in favor of the sine wave form. Fig. 6 shows a practical sine wave cable transmitter and generator.

The cable upon which these preliminary experiments were conducted is known as the "Coney Island" cable, belonging to the Commercial Cable Co., and extends from New York City, U. S. A., to Canso, Nova Scotia, having a length of 880 knots. This cable was laid in 1884, and consists of several sections of two different kinds of cable. Its total ohmic resistance is 13,700 ohms, and total static capacity 231.4 microfarads at 75° F. The two kinds of cable used are known as type "D" and type "E," each having 70 pounds of copper per knot. Type "D" has 115 pounds and type "E" 85 pounds of gutta percha per knot.

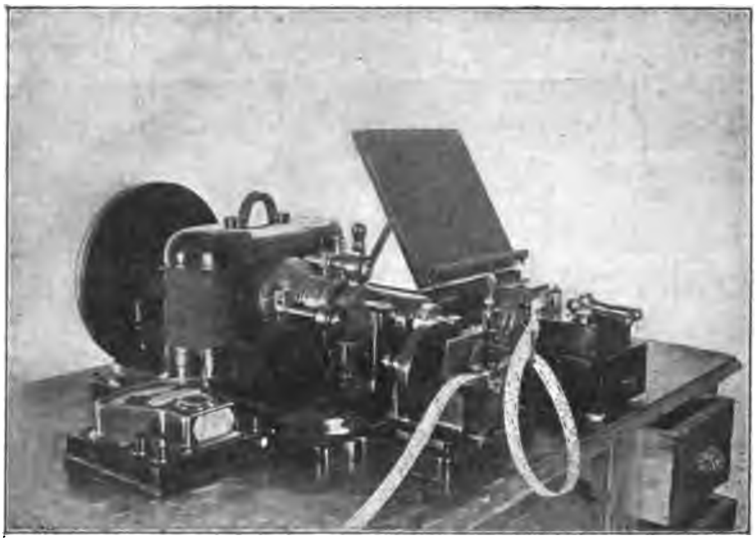


Fig. 6.—Cable alternator, transmitter and perforator.

Beginning at New York, the sections of the cable were approximately as follows:

New York,	Type "E"	127.7 knots.
	Type "D"	612.4 "
Canso,	Type "E"	140.5 "
	Total	880.6

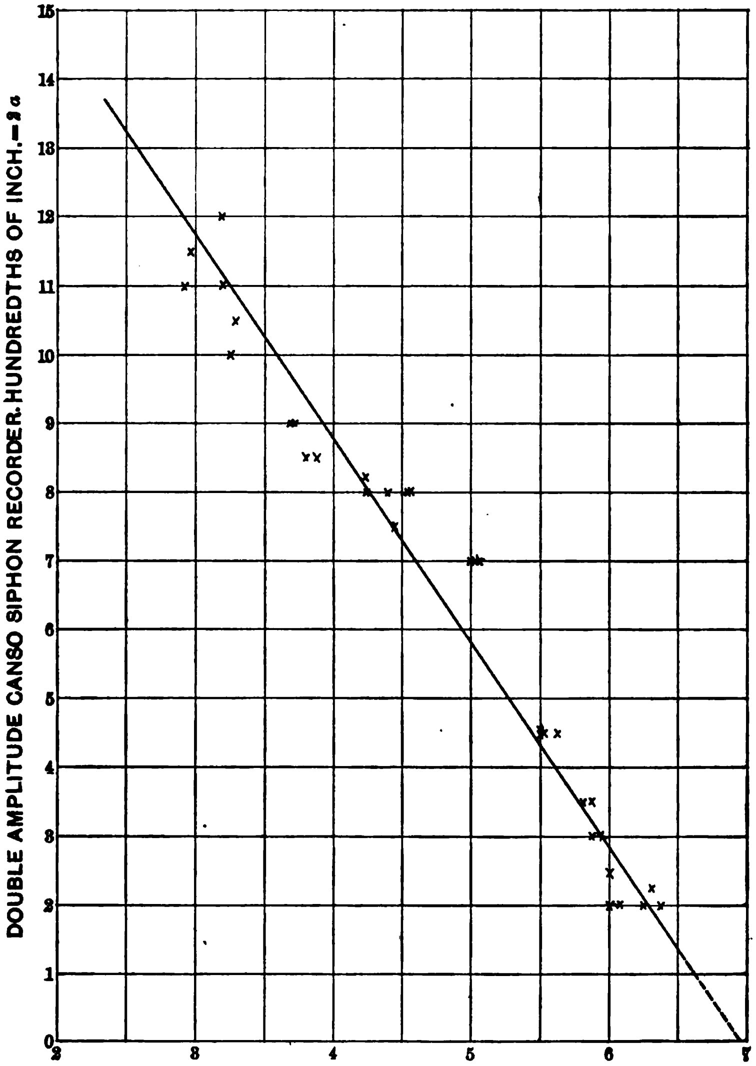


FIG. 7.—Relation between frequency and double amplitude of the receiving recorder with 80 virtual volts impressed at the transmitting end. C. I. cable simplex without condenser at transmitting end, and regular duplex with 50 microfarad condensers at receiving end.

This cable is ordinarily used with duplex working, but for the following experiment the cable was employed simplex without condensers at the sending end, which was New York, and with the regular duplex arrangement for receiving with condensers at Nova Scotia. The siphon recorder in Canso was adjusted in its normal working condition and not changed throughout the experiment.

Volts constant. Frequency and amplitude variable.—A simple alternating current, having an electromotive force wave like that in Fig. 5, was sent into the cable at constant voltage, and the frequency alone varied between the limits 3 and 6.4 waves per second. The record upon the Canso recorder showed a smooth wave approximating a sine wave, and the amplitudes of

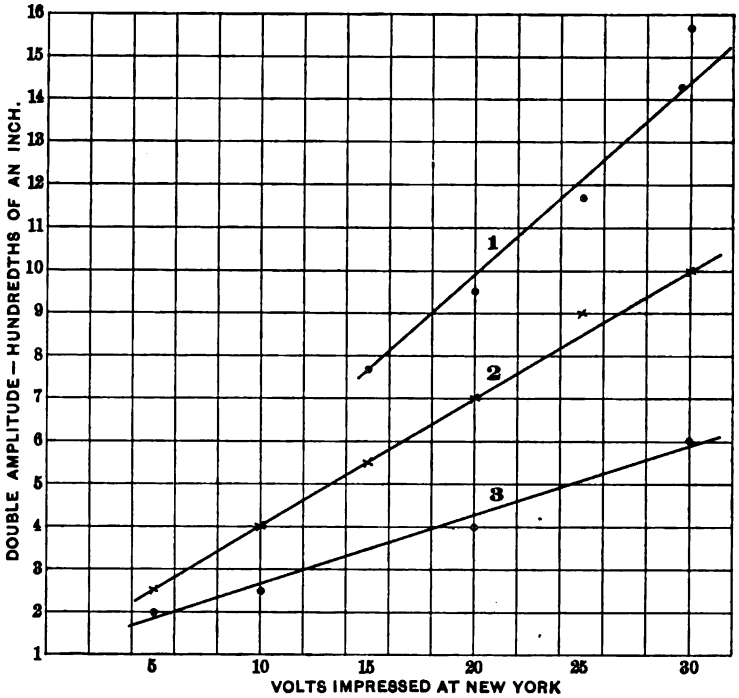


FIG. 8.—Relation between the impressed volts and the double amplitude of the received recorder. (1) Frequency equals 3.05, (2) 4.70, (3) 5.60. C. I. cable simplex without condenser at transmitting end, and regular duplex with 50 microfarad condensers at receiving end.

these waves were measured for the different frequencies, giving the result exhibited in Fig. 7. It is seen that the observed points lie within the limits of error almost upon a line whose equation is

$$2a = -2.97n + 20.64$$

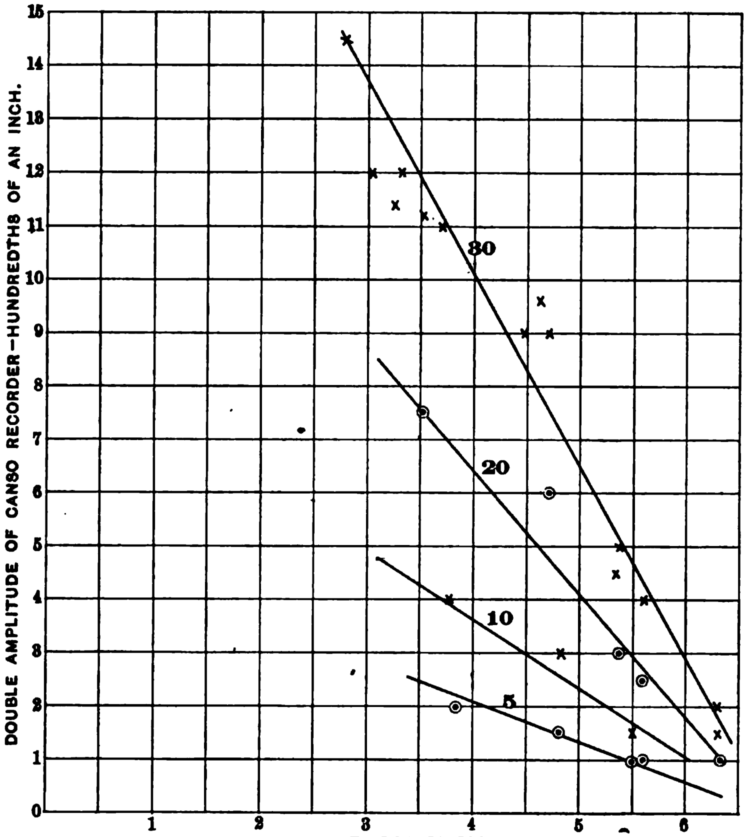


Fig. 9.—Relation between frequency and double amplitude of the receiving recorder for 30, 20, 10 and 5 volts. Circuits the same as in Fig. 7.

where a is the amplitude of the recorder and n the frequency. The pressure was constant throughout at 30 virtual volts. As the frequency increases the amplitude of the distant recorder decreases steadily towards a vanishing point approximately 7 waves per second. With this voltage and recorder adjustment it could not, therefore, be hoped to send signals with a greater frequency than 7—that is, at a greater speed than 227 letters per minute. One average letter with its space is taken as requiring exactly 3.7 semi-waves.

Frequency constant. Volts and amplitude variable:—To determine the effect of varying the voltage applied to the cable simplex without condensers upon the recorder at the distant end, the receiving end being used duplex with condensers in the regular manner, three series of observations were taken, each varying the voltage from 0 to 30. The frequencies were 3.05, 4.70 and 5.60 waves per second. The result is exhibited in Fig. 8, and shows that the amplitude of the received record is nearly proportional within the limits of observation to the pressure employed, for a given adjustment of the recorder coil.

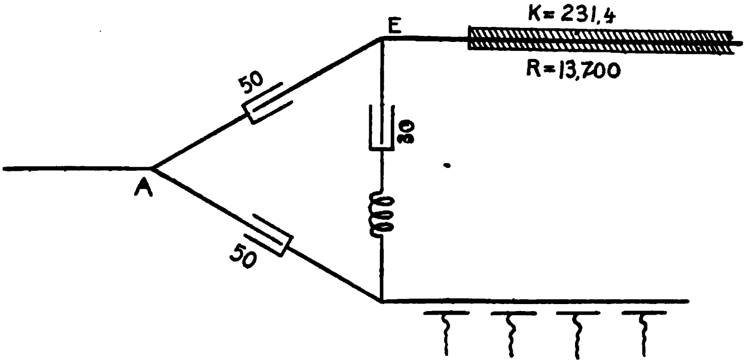


FIG. 10.—Duplex arrangement C. I. cable.

A more extended series was taken with the same arrangements of circuits, varying the frequency with constant volts, at 30, 20, 10 and 5 volts respectively. This result, Fig. 9, shows that the lines corresponding to the four voltages have approximately the same vanishing point at a frequency slightly less than 7.

To make a comparison between the automatic battery transmitter of the Cuttriss pattern, as used by the Commercial Cable Co. and the dynamo alternator, observations were taken with each instrument under the same conditions of the circuit, the recorder having the same adjustment in each case, beginning at low frequencies and increasing beyond the limits of legibility. The cable was used as in regular working, with the duplex arrangement. The results previously described in Figs. 7, 8 and 9 were obtained with no condensers at the sending end and regular duplex at the receiving end.

The arrangements of circuits and the values of the condensers employed are shown in Fig. 10 and the results in Fig. 11. Curve (1) represents the relation between the double amplitude of the record in Canso and the frequency of the battery reversals sent into the cable at New York, the battery employed being Fuller primary cells, which measured 36 volts on open circuit. With this voltage it is seen that the double amplitude of the excursions of the siphon were about 11/100 inch at a frequency of 3 and decreased to 1.5/100 when the frequency increased to 5.6. Curve (2) represents the result obtained with the shuttle-wound armature, which gave a wave represented in Fig. 5, and which was used in the experiments previously described. The pressure employed was 30 virtual volts between the apex of the bridge, *A*, and earth, *E*, Fig. 10. The observations did not extend through so great a range as that with the battery transmitter, and the volts were not the same, but the general shape of the curve is seen to correspond quite closely with the curve (1) throughout the range. It must be remembered that the previous experiments have shown that the ordinates of

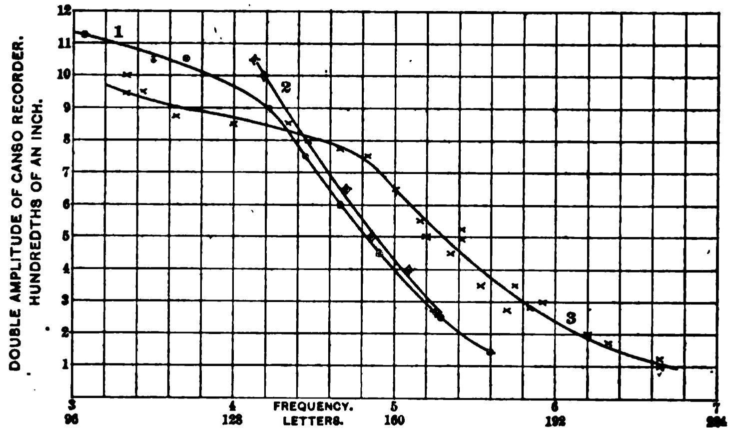


FIG. 11.

Relation between frequency and the double amplitude of the receiving recorder.

(1) The Cuttriss transmitter; battery 36 volts.

(2) The pointed wave alternator; 30 virtual volts upon apex.

(3) The sine wave alternator; 34.1 virtual volts on apex.

this curve (2) are approximately proportional to the voltage employed, so that it may easily be corrected to correspond to any desired voltage. Observations were also taken with a transmitter, furnishing a true sine wave under the same conditions, and the result is given in curve (3). There is a marked difference in the shape of the curve obtained with the sine wave from either of the other curves with the battery or the pointed wave alternator. At the low frequencies the sine wave gives smaller amplitude, and at the high frequencies larger amplitude than the other waves, the curves crossing each other at a frequency between 4 and 5. The pressure for curve (3) was 34.1 virtual volts at a point 75 ohms from the apex.

It will be interesting to note the various shapes of waves obtained under different conditions. Fig. 12 shows the shapes of waves both at the receiving and at the transmitting ends of the cable with the sine wave and with the pointed wave. A shows the pointed wave from the shuttle armature working on a simple resistance circuit, B the wave form of the same machine on the New York-Canso cable with the regular duplex arrangement. The record is obtained by inserting a recorder with a very low resistance shunt at the transmitting end of the cable, and the curve represents the wave shape which enters the apex of the bridge. C is the record obtained at the other end of the cable in Canso when the wave B is transmitted. D is the record at the transmitting end of the same cable when the sine wave is used, and E is the received record.

Battery reversals give curves just as nearly sine waves at the distant end as either C or E.

It appears therefore that approximate sine waves are received at the distant end of a long cable no matter what the shape of the alternating current transmitted.

CURRENT AND PHASE MEASUREMENTS.

The object of the following measurements was to obtain the law of variation of current and phase in the transmitting end of a cable with the frequency. To make these measurements a special set of apparatus was designed which included a switchboard so constructed that current and potential could quickly be read from the same instrument, since the time when the cable was available was limited. The measuring ammeter was a special one made by the Weston Instrument Co. consisting of one coil sus-

REPRODUCED FROM SIPHON RECORDS.

Actual size.

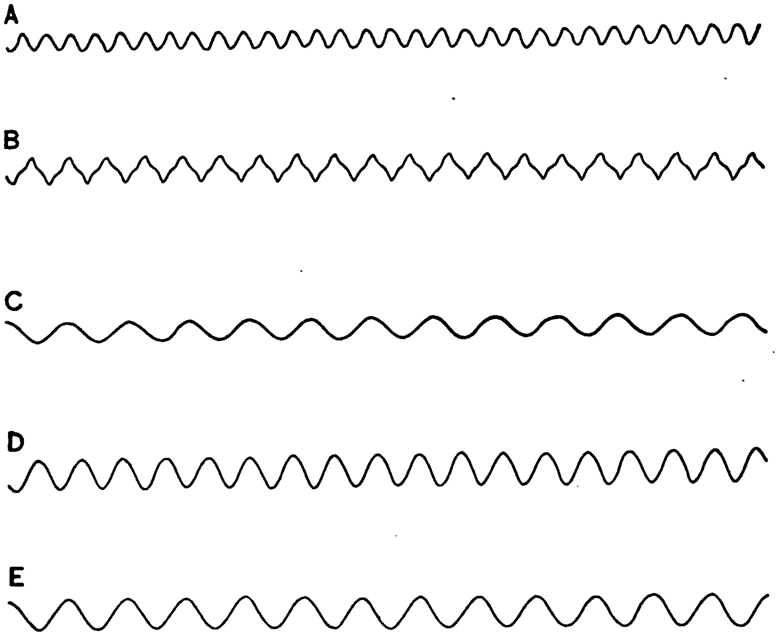


FIG. 12.

A. Pointed wave on local resistance.
B. Pointed wave in apex of C. I. cable, transmitting end.
C. Record of B at receiving end.
D. Sine wave in apex of C. I. cable, transmitting end.
E. Record of D at receiving end.

pended within a stationary coil as in the regular voltmeter, but the whole was immersed in oil to prevent the oscillations of the needle which occur when measuring such low frequencies. With this apparatus the current in the apex of the bridge was measured at various frequencies, the constant pressure at a point 75 ohms from the apex being 34.1 virtual volts, and the results obtained are shown in the table Fig. 13.

To compare these results with theory in the case of long submarine cables having resistance and distributed capacity, self-induction and leakage being neglected, curves have been calculated from the well known sine wave formula for the case of an infinite cable.

NEW YORK-CANSO CABLE.—(Fig. 13.)

Freq-quency.	Apex Current.		Cable Impedance.	Resultant Impedance Cable Condenser and 75 ohms.		Ratio Apex to Cable E. M. F.	E_3 At Apex + 75 ohms.	E_1 Cable E. M. F.
n	*Obs.*	*Cal.*	*Cal.*	*Obs.*	*Cal.*	*Cal.*	*Obs.*	*Cal.*
2.00	.0196	.01920	2162	3480	3556	1.613	34.1	20.75
2.33	.0229	.02145	2005	2980	3180	1.553	"	21.53
3.33	.0269	.02705	1676	2540	2520	1.458	"	22.72
4.08	.0302	.03080	1514	2260	2218	1.412	"	23.20
4.08	.0308	.03080	1514	2216	2218	1.412	"	23.20
4.42	.0325	.03240	1455	2100	2106	1.393	"	23.55
4.65	.0341	.03340	1418	2000	2042	1.382	"	23.66
5.00	.0347	.03485	1370	1966	1957	1.370	"	23.83
5.42	.0364	.03650	1313	1874	1868	1.357	"	24.00
5.66	.0372	.03762	1287	1833	1812	1.345	"	24.20
6.00	.0392	.03895	1250	1740	1752	1.333	"	24.33
6.66	.0418	.04145	1180	1630	1648	1.320	"	24.56

ANGLES OF ADVANCE C. I. CABLE.

n	Computed.	Observed.
8.2	58° 24′	55° 05′
4.0	56° 8′	49° 16′
5.0	55° 8′	44° 25′
5.66	54° 12′	48° 08′

$$i = E\sqrt{\frac{C\omega}{R}}\ \varepsilon^{-x\sqrt{\frac{CR\omega}{2}}}\ \sin\left\{\omega t - x\sqrt{\frac{CR\omega}{2}} + \frac{\pi}{4}\right\} \tag{1}$$

In this equation i represents the instantaneous value of the current at any point of the cable at a distance x from the origin and a time t. E is the maximum value of electromotive force applied to the cable. ε is the Naperian base. R is the resistance and C the capacity of the cable per unit length. ω is 2π times the frequency.

For quantities measured at the transmitting end of the cable x is zero, and equation (1) reduces to

$$i = E\sqrt{\frac{C\omega}{R}}\sin\left\{\omega t + \frac{\pi}{4}\right\}$$

or

$$i = I\sin\left[\omega t + \theta\right] \tag{2}$$

where I is the maximum current, and θ is the angle by which the current leads the electromotive force. This angle is constant equal to 45 degrees independent of the frequency.

The impedance of the cable is:—

$$Z_1 = \frac{E}{I} = \sqrt{\frac{R}{C\omega}} = \sqrt{\frac{R}{2\pi C}}\sqrt{\frac{1}{n}} = c_1\sqrt{\frac{1}{n}} \tag{3}$$

where c_1 is constant for any particular cable and the current:

$$I = \frac{E}{Z_1} = \frac{E}{c_1}\sqrt{n} \tag{4}$$

Measurements have been taken on two submarine cables of the Commercial Cable Co., the "Coney Island" cable from New York to Canso, Nova Scotia, and the "No. 3" Atlantic cable from Canso, Nova Scotia, to Waterville, Ireland. The data of the former has already been given and is:

R = 13,700 ohms
and C = 231.4 microfarads
Length = 880.6 knots.

The data for the latter, the Trans-Atlantic cable is:

R = 4895 ohms
and C = 914 microfarads.
Length = 2164 knots.

By substitution in (3) and (4) we have for the "C. I." cable

$$Z_1 = \frac{3060}{\sqrt{n}} \text{ and } I = \frac{E}{3060}\sqrt{n} \tag{5}$$

and for the "No. 3" Atlantic cable

$$Z_1 = \frac{925}{\sqrt{n}} \text{ and } I = \frac{E}{925}\sqrt{n} \tag{6}$$

(7) With 30 volts on No. 3 $I = .03245\sqrt{n}$

(8) With 40 volts on No. 3 $I = .04335\sqrt{n}$

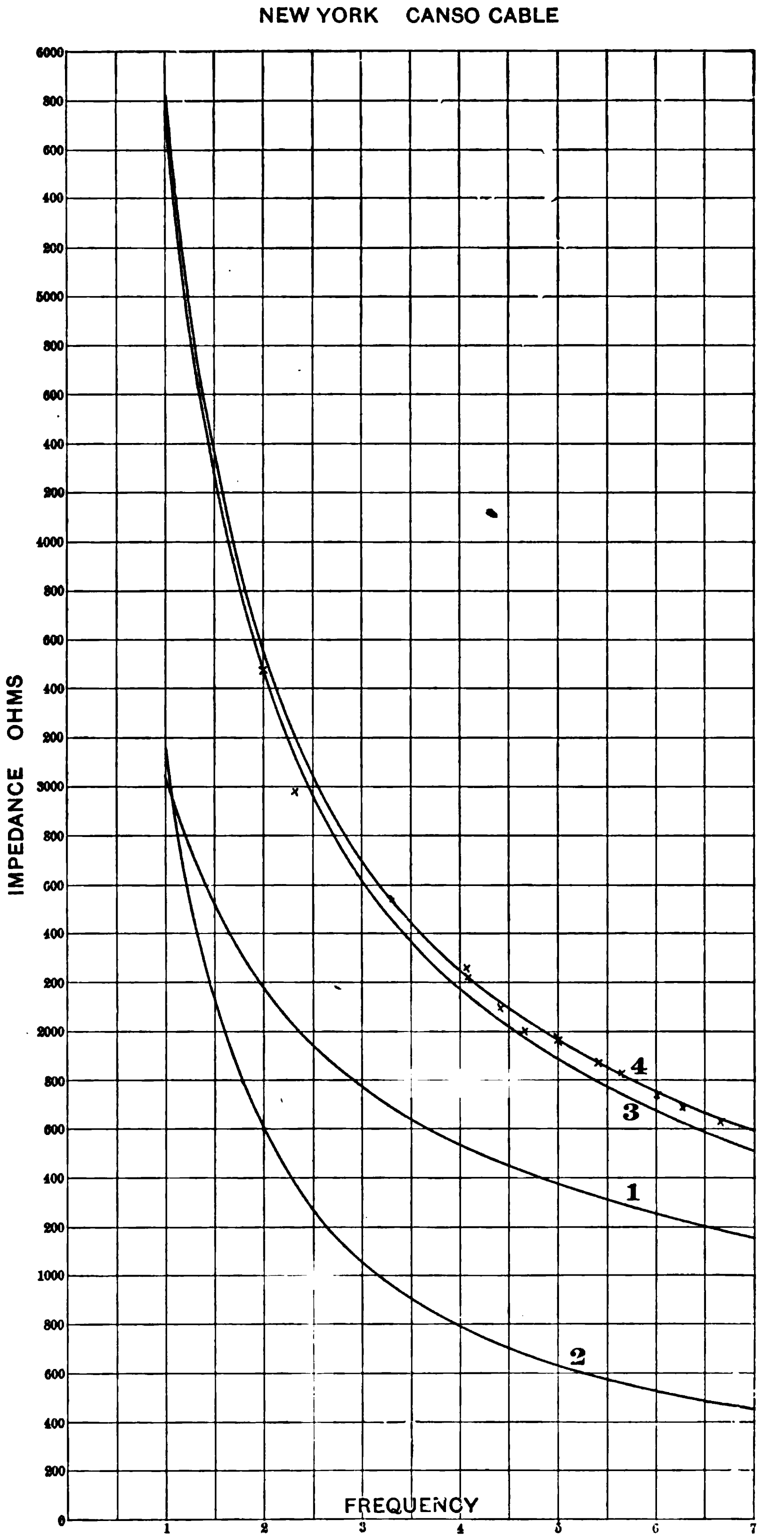


Fig. 14.—C. I. Cable.

(1) Calculated impedance of cable. (2) Calculated impedance of 50 mf. condenser. (3) Calculated resultant impedance from apex. (4) Calculated resultant impedance corrected for 75 ohm ammeter in circuit to apex.

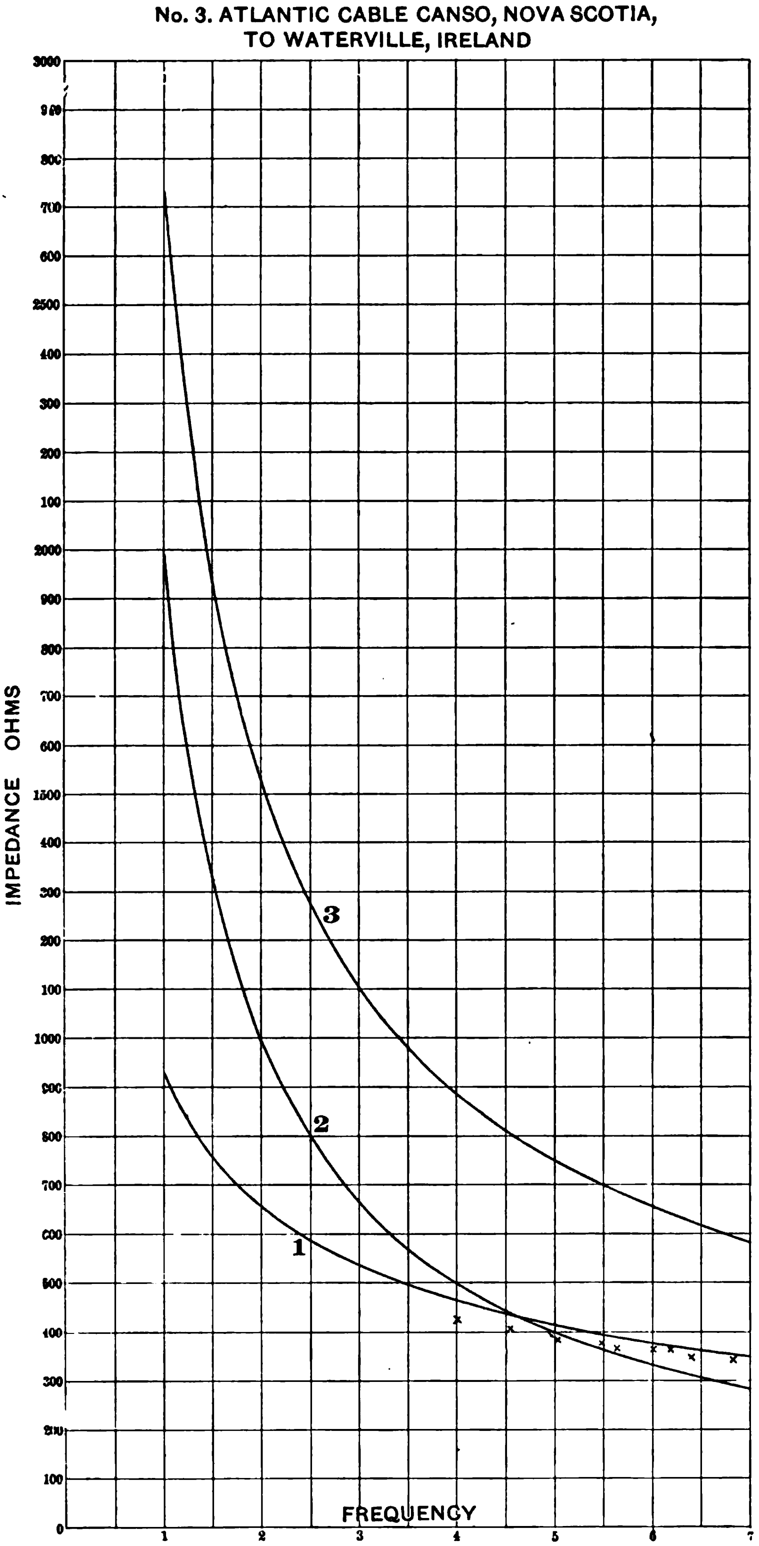


FIG. 15.—No. 3 Atlantic Cable.

(1) Calculated impedance of cable. (2) Calculated impedance of 80 mf. condenser. (3) Calculated resultant impedance from apex.

Curve (1) Fig. 14 represents the values of the impedance of the C. I. cable in ohms, calculated from equation (5), and curve (1) Fig. 15 the impedance of No. 3 Atlantic cable for different values of the frequency calculated from (6).

In taking measurements the regular duplex arrangement with condensers was employed and the voltage was sometimes maintained constant on the apex, and at other times on the cable itself, a Kelvin electrostatic voltmeter being used so that the currents were not disturbed. The delicate balance of the duplex bridge was not in the least disturbed by connecting the voltmeter between the end of the cable and the earth.

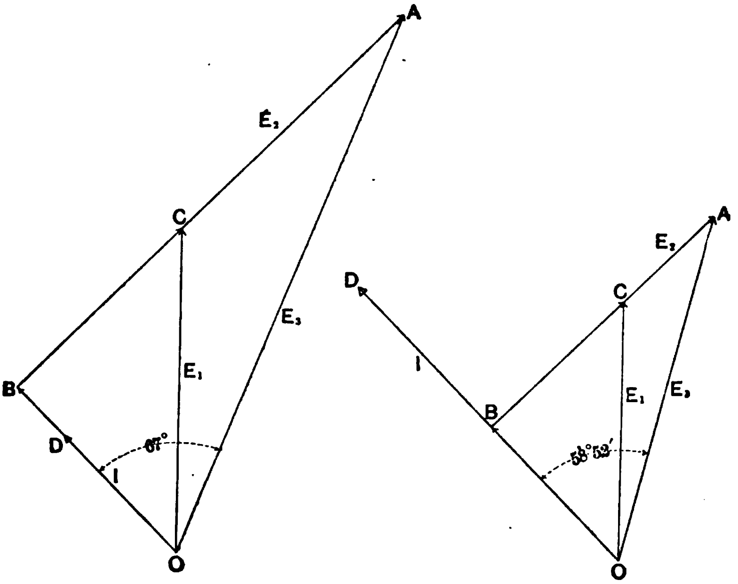


Fig. 16.

Electromotive force and current.
No. 3 cable.
O A = 53.6 volts.
O B = 21.2 "
O C = 30.0 "
A C = 27.9 "
A B = 49.1 "
B C = 21.2 "
O D = .15 amp.
$n = 5$

Electromotive force and current.
C. I. cable.
O A = 32.68 volts.
O B = 16.9 "
O C = 23.83 "
A B = 28 "
A C = 11.01 "
B C = 16.9 "
O D = .0347 amp.
$n = 5$

Scale of current O D for C. I. Cable is ten times that for No. 3 Cable.

For measurements upon the apex the impedance of the bridge condenser must be considered, and its impedance added geometrically to the cable impedance to obtain the resultant, since these quantities have in general different directions.

The line oc, Fig. 16, represents the electromotive force, E, applied to the end of the cable. In advance of this by 45 degrees is the current o I in the cable. The electromotive force E, is resolved into two components OB in phase and B C in quadrature with the current, each component being equal to $E/\sqrt{2}$ The electromotive force, E_2, of the bridge condenser is in quadrature with the current, and represented by C A. The electromotive force, E_3, applied at the apex is the sum of these components represented by O A. If O C the electromotive force on the cable is constant, then O A the electromotive force at the apex decreases as the frequency increases. The impedance diagrams

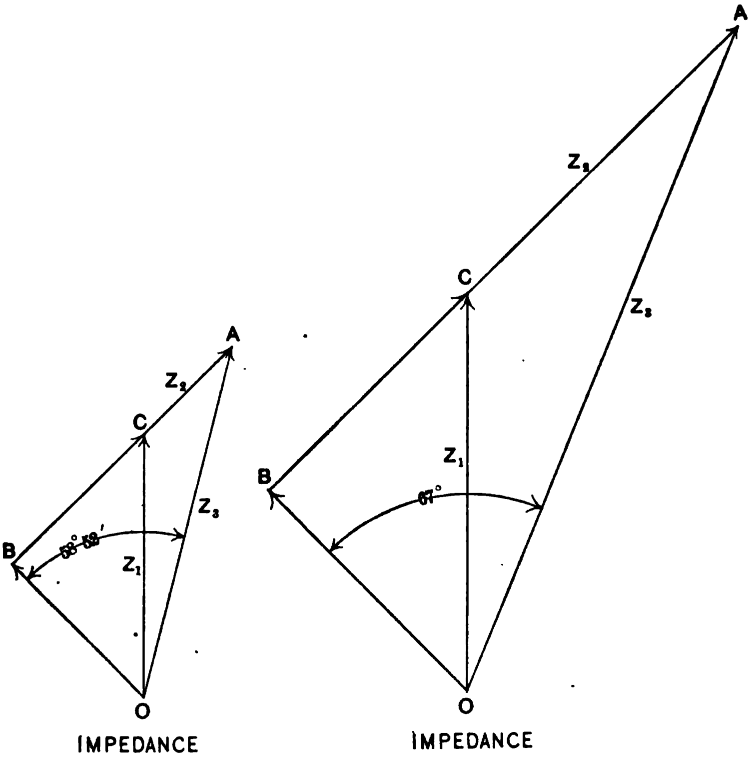


FIG. 17.

C. I. Cable.	
O A —	187.7 ohms.
O B —	969. "
O C —	1369. "
A B —	1605. "
A C —	636. "
B C —	969. "
n —	5.

No. 8 Cable.	
O A —	750. ohms.
O B —	292.5 "
O C —	414. "
A C —	398. "
A B —	690.5 "
B C —	292.5 "
n —	5.

Fig. 17 are obtained by dividing each line of the electromotive force diagrams by the current, and they are similar figures.

Fig. 18 represents electromotive forces calculated for the C. I. cable with 50 microfarad condensers. The line (1) represents

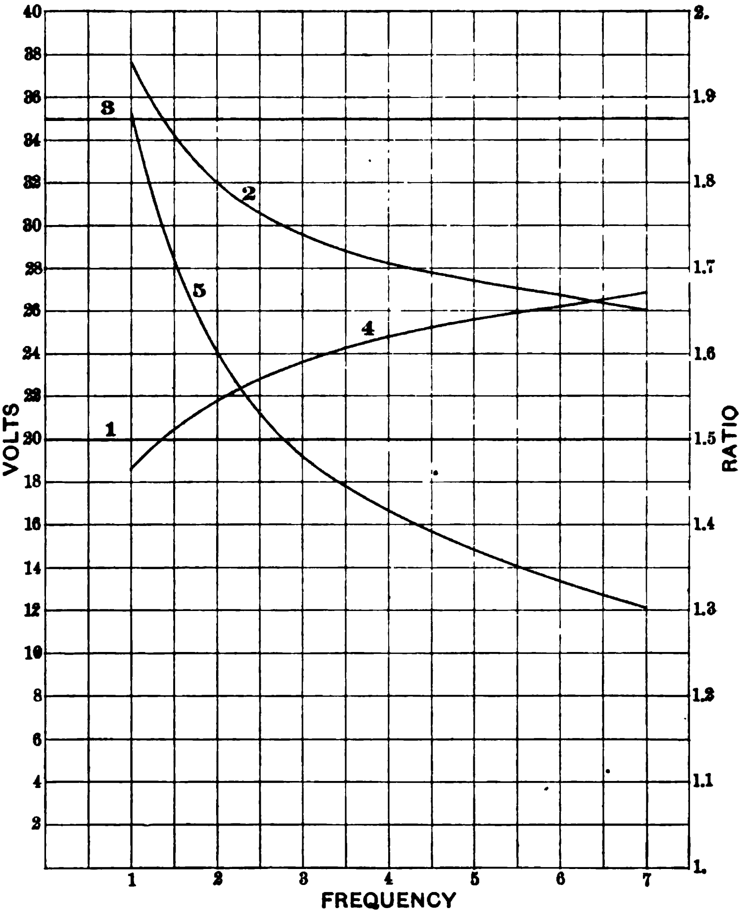


Fig. 18.—C. I. Cable.

(1) Twenty virtual volts on cable.

(2) Virtual volts required upon apex to produce 20 volts constant on cable.

(3) Thirty-five virtual volts at apex.

(4) Virtual volts upon cable due to 35 volts upon apex.

(5) Ratio of apex to cable volts.

20 volts applied to the cable, and is constant for all frequencies. Curve (2) represents the pressure required upon the apex to produce 20 volts constant on the cable; (3) represents 35 volts applied

constantly at the apex, and (4) represents the pressure which would be applied upon the cable as the result of 35 volts constant at the apex of the C. I. cable.

The ratio of the pressure at the apex to that upon the cable is constant for any particular frequency and independent of the pressure.

The values of the ratios of apex to cable volts at different frequencies are given in curve (5).

Fig. 19 shows a corresponding set of curves for the No. 3 Atlantic cable.

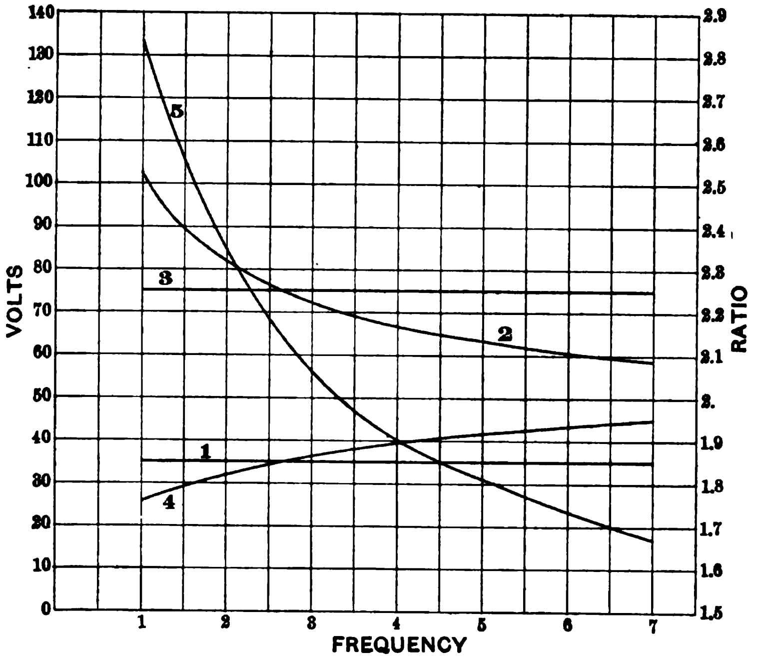


FIG. 19.—No. 3 Atlantic Cable.

(1) Thirty-five virtual volts on cable.
(2) Virtual volts required upon apex to produce 35 volts constant on cable.
(3) Seventy-five virtual volts at apex.
(4) Virtual volts upon cable due to 75 volts upon apex.
(5) Ratio of apex to cable volts.

Figs. 14 and 15 each have two curves (2) and (3) in addition to those described, which represent the calculated impedance of the condenser and the resultant impedance of cable and condenser for the C. I. cable and for No. 3 respectively.

The impedance of the condenser is:

$$Z_2 = \frac{E_2}{I} = \frac{1}{C\,\omega} = \frac{1}{2\,\pi\,C}\frac{1}{n} = \frac{c_2}{n} \tag{9}$$

For the C. I. cable 50 microfarad condensers are employed and

$$Z_2 = \frac{3180}{n} \tag{10}$$

For the No. 3 cable 80 microfarad condensers are employed and

$$Z_2 = \frac{1990}{n} \tag{11}$$

and this, combined with the cable impedance equation (3), gives a resultant,

$$Z_3 = \sqrt{\left(\frac{Z_1}{\sqrt{2}}\right)^2 + \left(\frac{Z_1}{\sqrt{2}} + Z_2\right)^2}$$

$$Z_3 = \sqrt{\frac{c_1^2}{n} + \frac{\sqrt{2}\;c_1\;c_2}{n\;\sqrt{n}} + \frac{c_2^2}{n^2}} \tag{12}$$

For C. I. cable

$$Z_3 = 1000\;\sqrt{\frac{9.38}{n} + \frac{13.75}{n\;\sqrt{n}} + \frac{10.16}{n^2}} \tag{13}$$

For No. 3 cable

$$Z_3 = 1000\;\sqrt{\frac{.858}{n} + \frac{2.602}{n\;\sqrt{n}} + \frac{3.96}{n^2}} \tag{14}$$

Fig. 20, curve (1), gives the calculated current in the apex of the C. I. cable for 34.1 volts, applied to the apex. This is calculated by dividing 34.1 by equation (13). Fig. 21 shows two current curves for No. 3 cable, calculated from equations (7) and (8) for 30 and 40 virtual volts constant on the cable itself.

Fig. 22 gives the calculated angles by which the current in the C. I. cable leads the pressure upon the apex for different frequencies. The pressure upon the cable leads the current by a constant angle of 45° in either cable, and the angle between

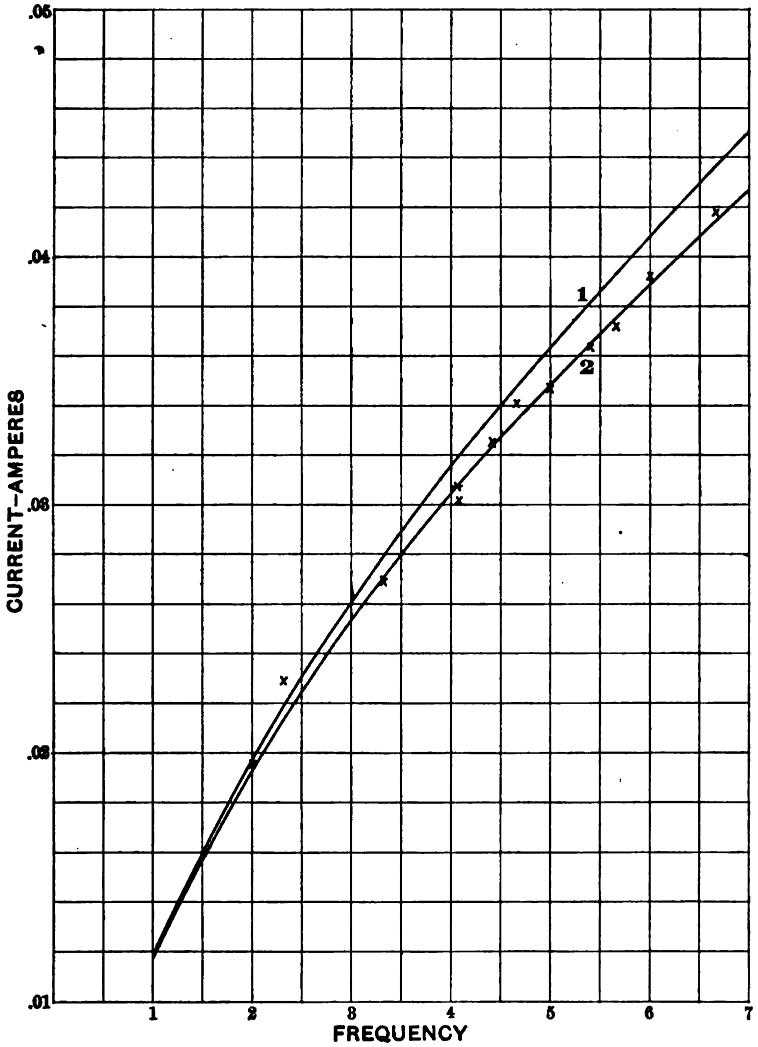


Fig. 20.—C. I. Cable.

(1) Relation between current at the apex and frequency with 34.1 virtual volts impressed at the apex.

(2) Corrected apex current with 34.1 virtual volts constant at a point 75 ohms from the apex.

the pressure upon the cable and upon the apex may be found by subtracting 45° from the ordinates of the curves.

When the measurements in the table 13 were taken on the C. I. cable, the ammeter was in the circuit before the apex, and the pressure read by a voltmeter connected not directly to the apex but to the other side of the ammeter, which had a resist-

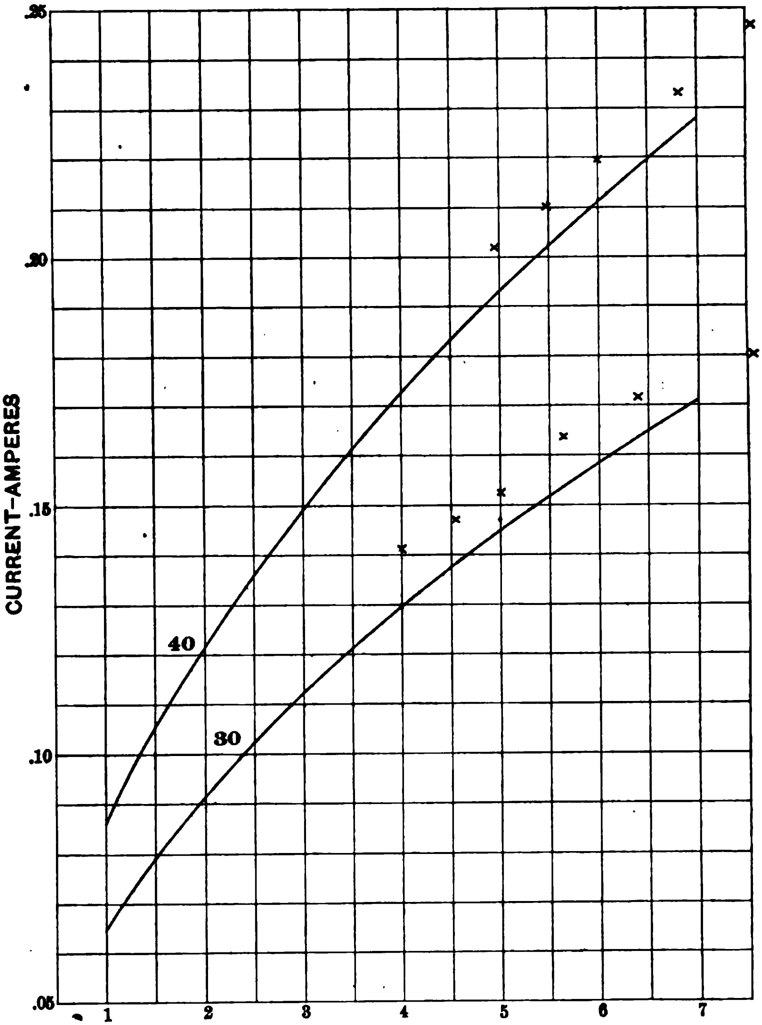


Fig. 21.—No. 3 Cable.

(40) Relation between current in the apex and frequency with 40 virtual volts constant upon the cable.

(30) Same as above, with 30 virtual volts on the cable.

ance of 75 ohms. The calculated curve (3), Fig. 14, represents the resultant impedance of cable and condenser from the apex. Curve (4) is calculated to represent the impedance including the 75 ohms of the instrument. It is seen that the observed values follow very closely the calculated curve (4). Since the pressure was maintained constant at a point 75 ohms from the apex instead of at the apex, curve (2), Fig. 20, has been calculated, and is seen to agree very closely with the current observations.

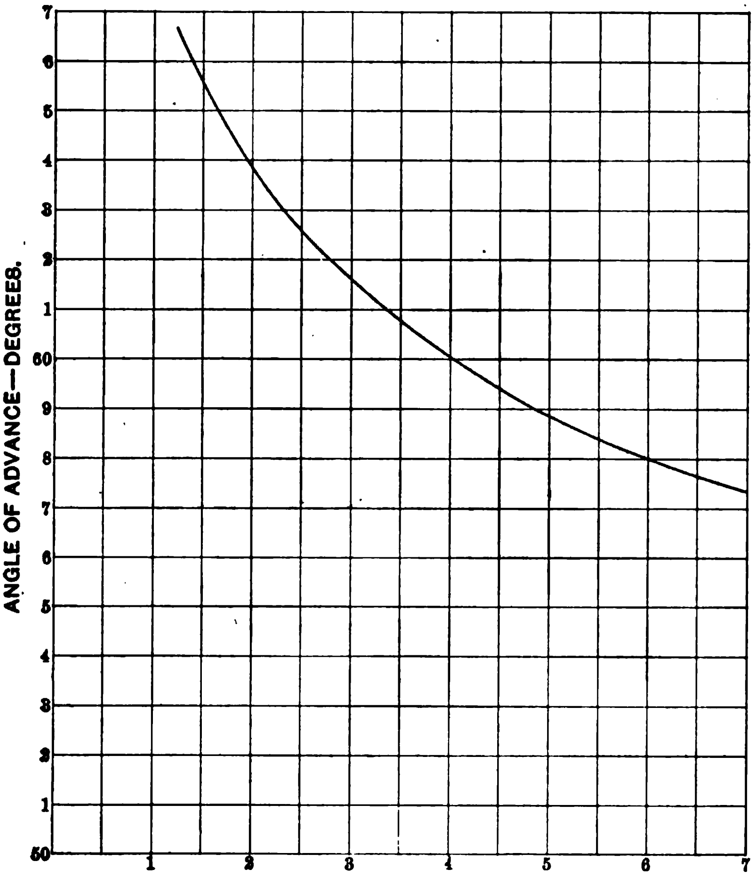


Fig. 22.—C. I. Cable.

Calculated angles between cable current and apex pressure.

Measurements were made by the three ammeter method upon the phase difference between the current in the apex of the C. I. cable and the impressed electromotive force. For this purpose a non-inductive shunt was connected from apex to earth and the current measured in the three circuits thus produced, *A* the current in the alternator, *B* in the apex of the bridge and *C* in the shunt. The resistance of the ammeter thus inserted was 75 ohms between the apex and the terminal of the shunt, which fact modifies the angle of phase between the current and electromotive force at the apex. Allowance has been made for this resistance in the calculated values as seen in the table Fig. 13.

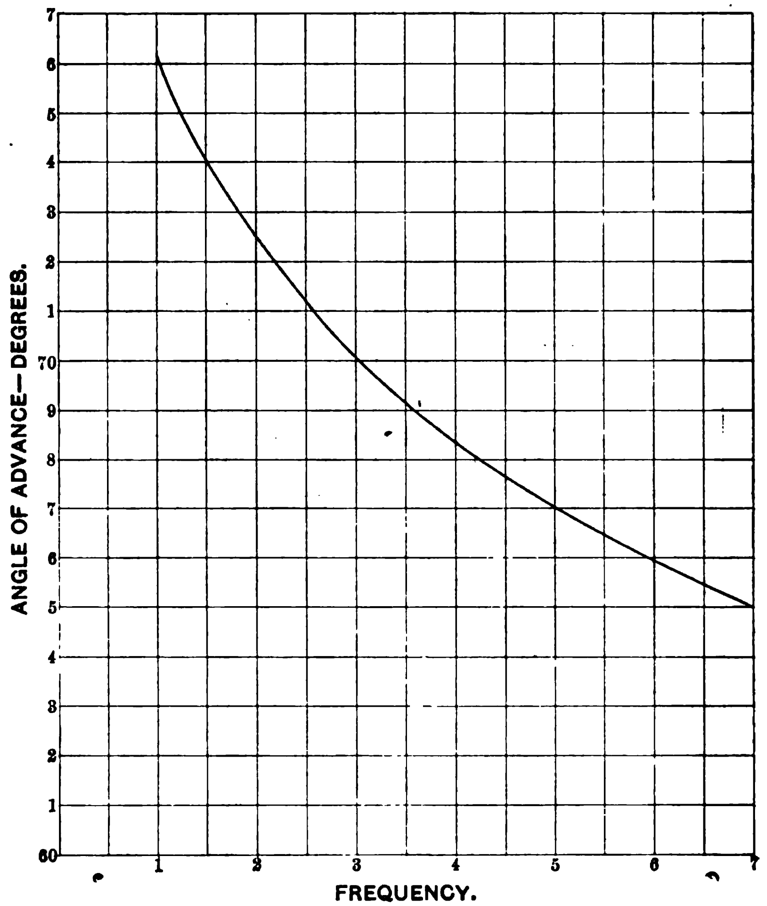


FIG. 23.—No. 3 Atlantic Cable.

Calculated angles between cable current and apex pressure.

The measurements upon No. 3 Atlantic cable are given in the table Fig. 24, and they are also seen upon the curves in Figs. 15 and 21. The agreement is not as close as in the case of the C. I. cable.

ON THE COMPARISON BETWEEN ELECTROMOTIVE FORCES EMPLOYED IN THE SINE WAVE AND THE ORDINARY BATTERY METHOD OF CABLE SIGNALING, AND ON THE INTERPRETATION OF THE TERM "EQUIVALENT VOLTAGE."

Since the speed of signaling or the number of letters per minute which can be transmitted and received by a given set of instruments on a submarine cable depends upon the magnitude of the electromotive force as well as upon the shape of the wave, it is important to note the differences between the physical phenomena which take place in the sine wave and battery methods. The speed is not proportional to the voltage by either method, but the increment becomes less and less as the pressure is increased, until it may be necessary to double the voltage to gain a few letters per minute. There is a practical limit to the voltage with any particular cable which it is not profitable to exceed, since the gain in speed is so slight. The limit of voltage which it is profitable to employ is not the same for the sine wave as for the battery method. To obtain the best speed with either system it should be worked at this maximum voltage point, which limit can only be determined by experiment. Before such a limit is reached, however, there are often other causes which prevent the best voltage from being employed. If a fault develops, a high potential at that point might effect the complete interruption of the cable. When the fault is discovered, it is customary to reduce the voltage to prevent entire interruption. There is at present such a fear of employing high voltage on submarine cables that a limit is set to the pressure at which cables may be operated, and this limit, for most of the cables of the

Cable E. M. F. E.	n	Apex Current Amperes Observed	Apex Current Amperes Calculated.	Cable Impedance Z Observed.	Cable Impedance Z. Calculated.	Ratio Apex to Cable E. M. F. Calculated	Apex E. M. F. Calculated
30	4.00	.141	.1286	425.5	466	1.900	57.0
	4.55	.147	.1401	408.1	436	1.845	55.4
	5.03	.151	.1450	397.5	412	1.806	54.1
	5.63	.164	.1540	365.9	389	1.761	52.9
	6.40	.172	.1637	348.8	367	1.705	51.15
	7.58	.180	.1770	333.3	335	1.635	49.0
40	4.96	.202	.1926	306.9	415	1.811	72.5
	5.48	.211	.2021	379.2	396	1.771	70.95
	6.00	.220	.2116	363.6	378	1.735	69.45
	6.82	.234	.2238	341.9	354	1.671	66.95
	7.58	.247	2361	323.9	335	1.635	65.45
53	6.17	.290	.2842	365.5	372	1.722	91.3

FIG. 24.—No. 3 Atlantic Cable.

world, is little more than 50 volts. Modern cables are subjected to a pressure of 5,000 volts alternating while in the cable tanks for a period often as great as half an hour. Thus the voltage at which the cable is tested is 100 times as great as that actually employed in signaling. The insulating material of an uninjured cable will withstand as high pressures as will ever be desired in signaling, but no factory test can guarantee the cable from mechanical injury after it is laid.

Since the voltage is limited upon a cable, it is evident that the system which can furnish the higher speed at the same pressure has the advantage, or that system which can furnish a given working speed with the lowest voltage is safest to employ.

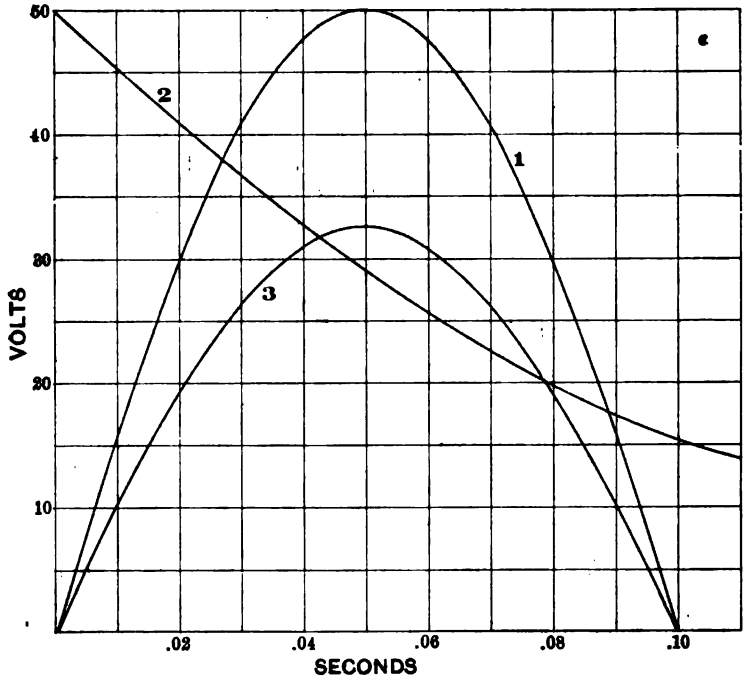


FIG. 25.—(1) Sine wave and (2) battery wave having the same maximum (3) Fundamental term or effective component of battery wave 2.

The true definition of equivalent voltage from this standpoint would then be such pressures as would equally strain the insulating material of which the cable is constructed.

The breaking strain of an insulating material not only depends upon the pressure to which it is subjected, but upon the time during which that pressure is applied. It is well-known that the dielectric of a condenser may break down in time under the same voltage which it has withstood for a considerable time. The maximum pressure therefore if only of brief duration should be allowed to be higher than a pressure which is continuous to cause the same breaking down strain in the dielectric. With a battery applied suddenly to a cable without condensers the whole pressure is upon the cable during the entire length of a signal, whereas with the sine wave method the maximum voltage is applied but a single instant and cannot be applied longer if desired.

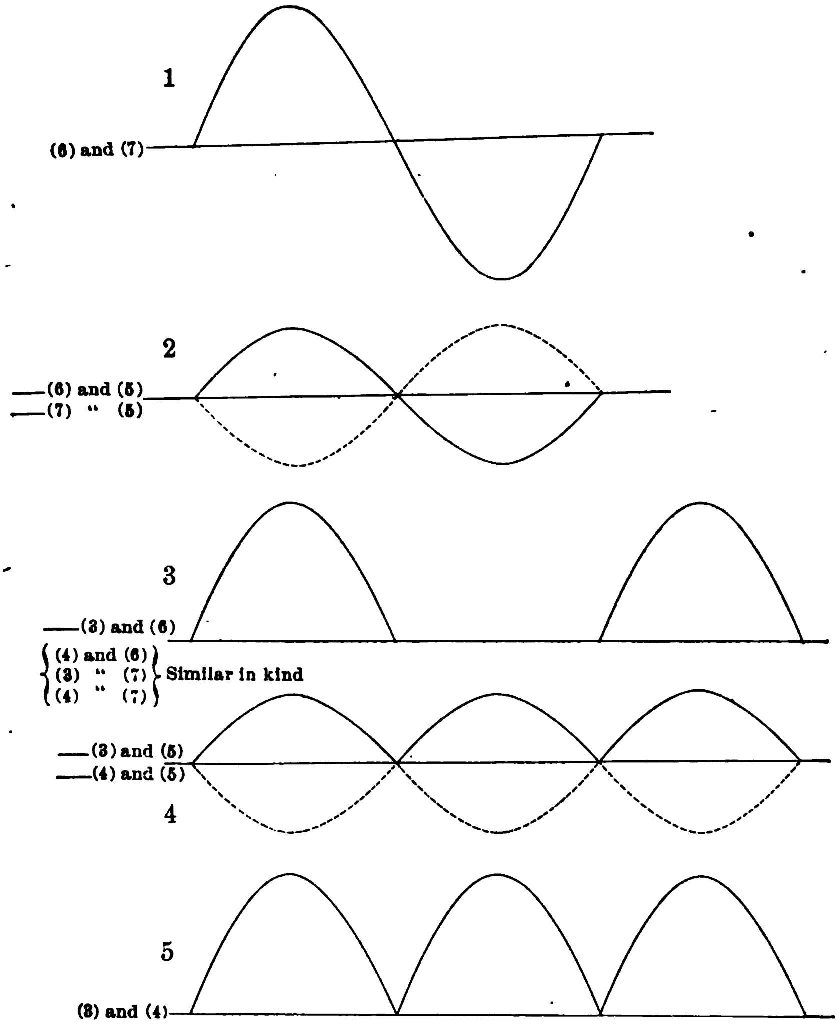


FIG. 26.—Forms of electromotive force obtained by connecting the various alternator brushes,

If air were the insulating material of a submarine cable it is known that the breaking strain is measured by the maximum voltage to which it is subjected, and is independent of the time during which this pressure is applied. When gutta percha or rubber are the materials used for insulation this time element should be considered. The effect, however, would vary for each particular compound and can only be determined by careful tests.

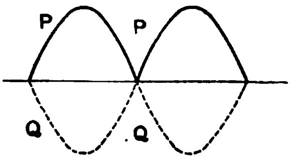


FIG. 27.

(3) Electromotive force in circuit (P) when commutator brushes are situated so as to reverse the circuit at time of zero electromotive force, that is, at the normal point of commutation for no sparking.
(4) Electromotive force in circuit (Q) under same conditions.

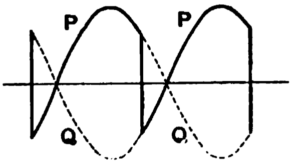


FIG. 28.

FIG. 28—P. Electromotive force in circuit (P) when commutator brushes are moved one-quarter ($\frac{1}{4}$) of a revolution from the normal position.
Q. Electromotive force in circuit (Q) under same conditions.

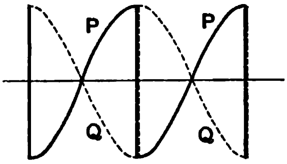


FIG. 29.

FIG. 29—P. Electromotive force in circuit (P) when commutator brushes are moved one-eighth ($\frac{1}{8}$) of a revolution from the normal point of commutation.
Q. Electromotive force in circuit (Q) under same conditions.

Equivalent voltages are therefore considered to be employed by the two systems when the same maximum potential difference between the core of the cable and the earth is attained at some time during each signal.

The fact that condensers are employed between the transmitter and the cable so modifies the pressure applied to the cable itself that the voltage and the methods of measurement are entirely different in the two systems. When a sine wave is employed, the pressure may be read directly from an electrostatic voltmeter between the end of the cable itself and the earth. Because they are sine waves the voltmeter reading multiplied by the square root of two or 1.414 gives the maximum value or top point of the voltage wave. If the maximum voltage on the cable is to be 50 then the voltmeter between the cable and earth should read $50/\sqrt{2} = 35.4$.

As has been pointed out above it requires a greater voltage than this applied between the apex of the bridge and the earth to produce the required pressure upon the cable because of the drop due to the impedance of the condenser. The apex voltage therefore depends upon the capacity of the condenser and the frequency.

When a battery is employed, the open circuit pressure of the battery is measured. If there is no condenser, then the cable is subjected to approximately the full battery pressure, which remains continuously applied as long as the battery is connected. There is a slight fall of potential through the battery, which, in ordinary practice, may be neglected, since the battery resistance is small compared with the impedance of the cable. When a condenser is used and the battery is suddenly applied to the apex of the bridge, the whole battery pressure, except the small loss already referred to in the battery, is applied between the cable itself and the earth since there is at the first instant no counter electromotive force in the condenser to reduce the cable pressure, the condenser being originally in the neutral state with no charge, and therefore no counter electromotive force. In time, however, the condenser acquires a charge, and with it a counter electromotive force which increases from zero at the first instant to a value which finally prevents all current flow in the cable. The pressure upon the cable, therefore, begins at the battery pressure and rapidly diminishes with time until it has practically vanished in a fraction of a second. In either case whether condensers are employed or not, the maximum pressure to which the cable itself is subjected is approximately equal to the battery voltage. The difference is that with condensers this pressure is momentary, while without them it is continuous. The phenomena with a sine wave and a battery wave depend entirely upon the manner in which the electromotive force is applied. When applied suddenly as with a battery the condenser has not had time to acquire a charge or counter electromotive force before the maximum pressure is reached. With a sine wave beginning at zero and increasing gradually to a maximum, the condenser acquires a charge before the maximum point is attained, and therefore the apex pressure must exceed the cable pressure. The rule for obtaining equivalent voltage in the two methods may then be stated by the answer to the following question: "What sine wave electromotive force steadily applied to the sending end of a cable, as measured by a properly calibrated electrostatic voltmeter inserted between the sending end of the cable and earth, produces the same maximum electromotive force in each wave as the maximum electromotive force applied to the cable by an earth connected battery, either directly as in ordinary simplex working without sending condensers; or to the apex of the bridge, and therefore through condensers, as in duplex working?"

The answer is that the virtual alternating pressure or sine wave electrostatic voltmeter reading, which is 70.7 per cent. of the full battery voltage produces the same maximum pressure in each alternation or wave as the battery. For example, a sine wave which produces an electrostatic voltmeter reading of 35.4 volts between the cable and earth is equivalent to a battery of 50 volts whether applied to the cable directly or through condensers.

WHY THERE IS A GAIN IN SPEED USING THE SINE WAVE INSTEAD OF THE BATTERY AT THE SAME VOLTAGE.

The received waves through a long submarine cable are approximately sine waves, whether true sine waves or even battery reversals are employed at the transmitting end. With the same maximum voltage at the transmitting end of the cable, however, the amplitude of the wave at the receiving end is greater when the sine wave is employed, which means that more energy is transmitted by the cable. This is equivalent to attaining higher speed, since with the same speed as the battery transmitter the amplitude of motion and definition is greater; but by tightening the suspensions and quickening the natural period of the recorder, the same definition and amplitude is obtained at a higher speed.

The reason why more energy is transmitted is plain. A wave such as battery reversals send to the cable may be analyzed by Fourier's theorem into a number of component simple sine waves, which consist of a fundamental wave and harmonics having higher frequencies. Lord Kelvin's theory maintains that it is only the first or fundamental term of such a series of waves which pass through the entire length of the cable with an appreciable effect, and this theory is fully confirmed by the experiments already described as a reference to the curves in Fig. 11 will show. If, for example, the fundamental wave had a frequency of 5, the double amplitude of the recorder would be about .065 inches, which is a working value. The harmonic having double the frequency of this, viz., 10, would not have any observable effect upon the distant recorder, as this is beyond the limits of the observed curve (3), which extends to a point about a frequency of 7, where the double amplitude of the record is less than the width of the recorder line. It is therefore only the fundamental sine wave component of the battery wave which is useful in operating the receiver, and it is evident that this fundamental wave has a maximum much below the maximum point of the battery wave. Let (1) Fig. 25 represent a sine wave which has the same maximum point as the battery wave (2). The only effective portion of the battery wave, as far as the distant receiver is concerned, is the fundamental term in its analysis, which may be represented by the sine wave (3), which evidently has a maximum point considerably lower than the top of (1) or (2).

The strain upon the dielectric of the cable is approximately the same for the battery wave (2) as for the sine wave (1), which has the same maximum value, but the effectiveness of the battery wave upon the distant receiver is only equivalent to the smaller sine wave (3).

It thus appears that the many harmonics necessary to make the battery type of wave, are entirely useless in signaling, and introduce an extra charge into the cable which must be discharged between signals.

EXPERIMENTS AFFECTING THE CHARACTER OF TELEGRAPHIC CABLE SIGNALS.

The following experiments were made upon the No. 3 Altantic cable of the Commercial Cable Co. at Waterville, Ireland. The object was to determine the effect upon the character of the signals produced by modifying in various ways the simple sine wave elements.

METHODS OF DISCHARGING THE CABLE.

a. The ordinary method of battery signaling connects the cable to earth during the latter portion of each signal, which permits the discharge of the cable and separates the successive signals

The sine wave naturally separates the successive signals and tends to discharge the cable since the electromotive force reduces to zero for each impulse while the cable is connected to earth. If the cable is not connected to earth between letters and words it is difficult to distinguish where the letter begins and ends upon the record. To furnish a path for the discharge of the cable several methods were tried. A shunt resistance was directly connected from the apex to the earth, which furnished at all times a path for the discharge of the cable. This arrangement required that the generator should maintain the terminals of this shunt at the voltage desired upon the apex. This causes a load upon the generator in addition to that required for signaling which increases more and more as the value of the shunt is decreased. In practice on the Atlantic cable it was found that the value of the shunt required to produce sufficient discharge is so small that the power reqnired from the generator is out of proportion to the work of signaling proper.

With the large capacity of an Atlantic cable it is best to have a direct earth connection without resistance. This is ordinarily accomplished in the battery system by means of a sounder transmitter in conjunction with the automatic transmitter, which disconnects the battery and connects the cable to earth during the latter portion of each signal.

This may be accomplished by the sine wave transmitter if it is connected to the sounder transmitter in the following manner. The electromagnets of the sounder transmitter are operated by local battery power governed by the perforations in the tape which passes through the synchronous transmitter geared to the generator. In place of the signaling battery the armature of the sine wave alternator is substituted. The size of the perforations in the tape governs the relative durations of earth connection to current impulse.

The above method utilizing the regular sounder transmitter produces the required result, but it is simpler and more reliable to entirely dipense with the sounder transmitter and use the sine wave transmitter alone, which accomplishes what the present automatic and the sounder transmitter together accomplish. The method referred to is the transmitter already described employing three separate lines of holes in the transmitting tape. Thus the number of contacts is reduced from six to three, four of the six being required for the sounder transmitter. Of a large number of methods of accomplishing this result by the use of relays, rectifiers, etc., the method employing three hole tape which entirely dispenses with any form of relay, with its continuous source of errors and delays, experience has shown to be one of the most simple and reliable.

b. In order to ascertain whether there is any advantage in making an earth connection between successive signals of a single letter a ring was mounted upon the shaft of the generator, so that the cable and earth could be connected during any portion of a semi-cycle desired. This is equivalent to changing the size of the perforations in the tape but affords an easier means of varying the earth contact. A series was taken, using the same transmitting slip and varying the degrees of earth contact from 0 to 60 degrees or one-third semi-cycle. These records were carefully compared and reported upon by the expert operators in Canso, who were purposely not informed of the changes that were being made, with the result that the best signals were reported when little or no earth was employed between successive signals.

An experiment was made to determine whether the different letters of the cable alphabet are transmitted and received with equal facility, and if not, which letters of the alphabet are most legible at the highest speed. It is understood that operators are now trained to read letters which have successive signals of the same polarity without detecting the individual signals, and indeed prefer such letters; but the following conclusive experiment was devised to determine the relative value of the so-called cross-letters of the alphabet, such as "a," "n," "k," "r," etc., having successive signals of alternate polarity, in comparison with letters like "m," "g," "h," &c., having successive signals of the same polarity. Two lists of English words were prepared, one consisting of cross letters only, such as "acre," "nearer," "center," "trace," &c., and another of other words, such as "should," "how," "plow," etc., and no information as to the object of the experiment or of the words being transmitted was communicated to Canso. The messages were then transmitted at a rate higher than they could be read, and the speed gradually reduced until the extreme limit of legibility was reached. The result of these tests was that the cross letters could be read at a considerably higher speed. This experiment was repeated several times, different words being employed, with the same results. The above is an inherent defect in the present alphabet, an ideal alphabet being one in which each letter has the same limit of legibility.

AN AUTOMATIC TRANSMITTER IN WHICH THE ELECTROMOTIVE FORCE APPLIED TO THE CABLE IS MODIFIED FOR CERTAIN LETTERS ONLY.

Since the cross letters of the alphabet have a higher speed limit than the other letters, it seemed desirable to make the same transmitter send the latter letters with the electromotive force somewhat modified without changing the cross letters. One method of easily modifying those letters which have two or more successive sinuses of the same polarity is to change the electromotive force of the second and succeeding sinuses in magnitude only without changing its direction or sine wave shape. Plate III A shows a record made by the siphon recorder on a local circuit with the transmitter thus modified, where it is seen that the second and third dots of the letter "b," instead of being the same size as the first dot, as they ordinarily are on a local circuit, are considerably reduced. On the other hand, the letter "c," for example, and all the other cross letters, remain unaltered. In the letter "h" the last three dots are small and the first large. This transmitter being entirely automatic, the relative size of the first and successive signals of these letters is under control, even without stopping the transmitter, by an adjusting rheostat. With this transmitter a series of tests were made on the Atlantic cable, the receiving experts in Canso being uninformed as to the nature of the experiment. It was found easy to change entirely the appearance of the modified letters at the receiver, from their normal appearance with rheostat open, to a signal unrecognizable when the succeeding sinuses of the letters were practically reduced to zero by a change of the rheostat. The letter "h," for example, which normally rises from the zero line of the recorder at each successive signal, was made to remain horizontal or to descend, as desired. By this method it is possible to improve some of the letters, but others, such as "l" or "y," are apparently no better, if as good.

Another method of modifying certain letters without altering others was tried with the three-hole tape transmitter, which consisted of applying a battery instead of the armature of the sine wave alternator to the two signaling brushes. Because the holes in the perforated tape are so large that consecutive perforations on the same side cut away all the paper between the holes allowing the brush to make continuous contact through two or more consecutive perforations, the cable only receives a single impulse at the beginning of a succession of dots or dashes of the same polarity due to the sending condensers which quickly stop the current. The cable, however, receives a sufficient charge to cause the receiver to give the letters so affected their normal appearance. Evidently the "cross letters" are not affected thereby, being the same as with the ordinary battery transmitter. An example of a record received by this method is seen in Plate III, B.

The results thus far obtained upon this cable indicate that, everything considered, the simple sine wave signals unaltered in any way give, on the whole, the most readable signals throughout the alphabet.

TRANSFORMERS.

It is a natural step in the development and use of the sine wave of electromotive force for cable signaling to employ ordinary alternating current apparatus, among which the closed circuit alternating current transformer occupies a conspicuous place. It was not until after a transformer had been obtained, with a view of using it in transmitting messages, that the good results obtained with transformers in England by Mr. Dearlove came to our notice. The transformer used was a commercial one, specially wound with five separate coils, designed to operate on 1,000, 500, 500, 50, and 50 volts respectively.

In using the transformer for signaling, the alternator is connected directly to the primary, while the secondary, which may be considered as the source of the transmitting electromotive force, is connected directly between the apex of the bridge and earth. This gives a permanent low resistance connection between the cable and the earth and dispenses with any form of earthing device. The general effect of the transformer is to give a natural curb to the impulses transmitted through it, since a single positive sinus in the primary circuit produces both a negative and a positive sinus in the secondary circuit whose values depend upon the inductance and the frequency. Plate III C shows a record received in Canso, using a transformer for transmitting at New York. It is seen that the letters like "h," which usually rise from the zero line, in this case descend towards it. With an adjustable inductance, the general characteristics of the received record can be changed materially and at will, so that the "s" or "h" may either rise from the zero line, descend toward it, or remain approximately horizontal.

To determine whether the magnitude of the current received through the Atlantic cable is sufficient to operate a receiving transformer, messages were sent from Canso and received in

Waterville. The regular duplex arrangement was retained, and the primary of the transformer inserted where the siphon recorder ordinarily is, the condenser in series with the recorder being removed. The particular winding of the transformer then available was not suitable for obtaining the best results over the cable, but records were obtained which could be read, and the above is cited as showing that there need be no hesitation in employing transformers as far as the magnitude of the currents is concerned.

The substitution of comparatively inexpensive transformers for the condensers now required in duplex working would be an advantage from many standpoints. In the future development of cable telegraphy, both the transformer and the condenser will probably play an important part.

CONCLUSION.

The real test of cable apparatus is its efficiency for continuous work in the hands of average cable operators, and in the development of the details of the transmitter its use in actual traffic on the Atlantic cable for several days at a time has been of great value.

One of the radical features of the transmitter shown is the employment of small steel brushes, making contact through the perforations in the tape with a platinum cylinder having a corrugated surface. The present automatic transmitters of the Wheatstone type, make the electrical contacts at a point away from the transmitting tape by means of a system of levers. In using the alternating current always interrupted at the zero point there is not the same objection to the use of brushes due to sparking which is the case when a direct current is suddenly broken at a high voltage. Any system of levers is impossible for very high speed telegraphy, and the elements of a transmitter could hardly be more simple and direct acting then making contact through the tape with some form of brushes. It is evident that either form of transmitter may be used with the cable alternator, but the brush form as now perfected is preferred.

The sine wave transmitter removes the necessity of any form of battery power for a cable station. The same armature furnishes the power for hand transmission as well as automatic, and the same convenience in switching from one to the other is maintained as at present. The present tendency in telegraphic engineering is to remove all forms of primary batteries as a source of power, and the sine wave alternator combines this advantage with the most efficient form of wave for signaling.

As evidence of the character of the signals produced by the sine wave method as compared with the battery method, a few examples have been selected from signals received at Waterville, Ireland, transmitted from Canso, Nova Scotia, and from signals received in Canso transmitted from New York, which are appended herewith in Plate I.

Plate II shows three examples of battery signals received in Ireland transmitted from Nova Scotia.

Plate IV shows some comparative sine wave and battery signals showing the same message transmitted from New York to Nova Scotia.

Plate V. shows a sine wave record at the receiving end and at the transmitting end of the C. I. cable.

In closing this paper it is desired to record our appreciation of the very unusual facilities placed at our disposal by the Commercial Cable Co. of New York, extending over a period of nearly two years, and the valuable assistance rendered by their engineers.

APPENDIX.

SOME ELECTROMOTIVE FORCES OBTAINABLE WITH THE TRANSMITTER.

In the previous explanation of the transmitter the brushes were so placed that the signals were transmitted in the normal way. The effects of shifting both the commutator and transmitter brushes furnish a variety of electromotive forces. Referring again to Fig. 3, two additional collector rings C and D (not shown in the diagram) are placed upon each transmitter so that the simple alternating current may be obtained directly from the whole armature. The rings are connected one to each terminal of the armature winding C, being joined to segment (1), and D to (2) commutator A. There are then upon the shaft the divided ring A and three collector rings, B, C and D. Upon A bear two diametrically opposite brushes (3) and (4), and upon B, C and D, three brushes (5), (6) and (7) respectively. Figure 26 shows a series of electromotive forces obtained by joining any two of the five brushes (3), (4), (5), (6) and (7). By connecting brushes (6) and (7) a simple alternating electromotive force from the whole armature is obtained. By connecting (6) and (5), or (7) and (5) simple alternating electromotive forces are obtained from the half armature, exactly opposite in phase. When the commutator brushes (3) and (4) are set in the neutral position, curves 4 show the electromotive forces obtained by joining (3) and (5) and (4) and (5) which are rectified electromotive forces of the half armature. This is the combination used for cable signaling.

Figs. 27, 28 and 29 represent the electromotive forces obtained at the transmitter brushes P and Q for three different positions of the commutator brushes (3) and (4), the connections being as shown in Fig. 3. The heavy line represents the electromotive force at brush P and the dotted line at brush Q. Fig. 27 shows the electromotive force when brushes (3) and (4) are in the normal or zero position of commutation, Fig. 28 when they are revolved one-eighth, and Fig. 29 a quarter of a revolution from the neutral position.

Three series of curves are shown in Figs. 30, 31 and 32, each set corresponding to the same position of dynamo brushes (3) and (4), as the electromotive force curves Figs. 27, 28 and 29 respectively. These series show the resulting electromotive forces obtained when the transmitting tape is used, having simple alternating perforations, and each begins and ends with the simple harmonic electromotive force, the succeeding curves representing the effect of shifting the transmitter brushes P and Q one sixteenth of a cycle longitudinally along the tape by means of the micrometer screw. The actual distance which the brushes move corresponding to the consecutive curves is 1/80 of an inch. The heavy portions of the curves represent that which is transmitted through perforations in one side of the tape, and the dotted portions through the opposite side. Three series of curves were obtained upon the siphon recorder with the sine wave transmitter on a local circuit, and are exhibited in Figs. 33, 34 and 35. With sudden changes in the electromotive force the siphon moves across the tape without making a mark. The series exhibits a close similarity to the theoretical curves, Figs. 30, 31 and 32.

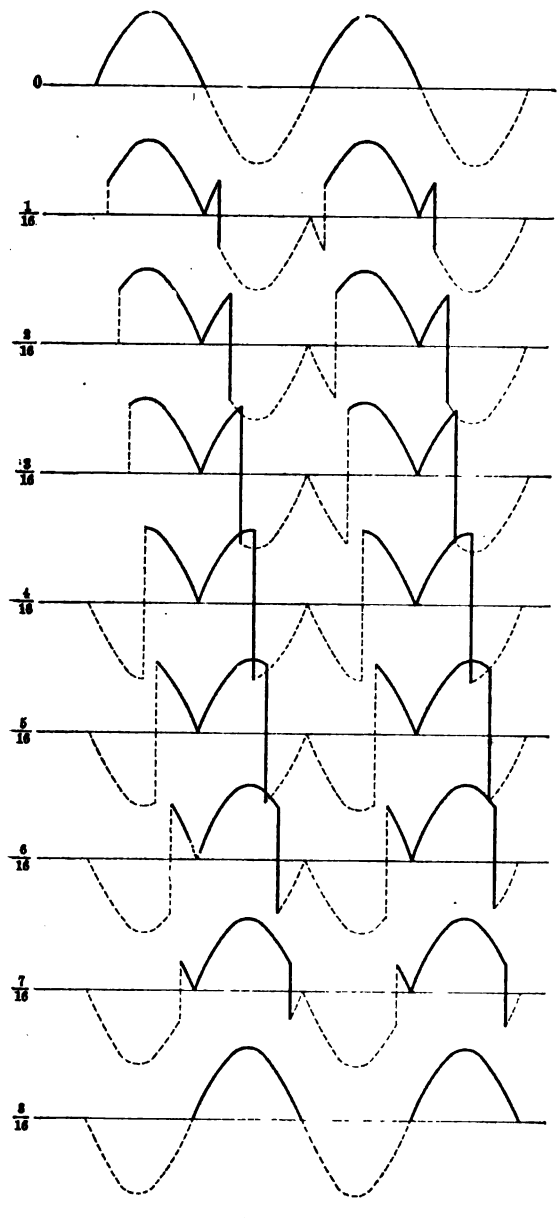


FIG. 30.

The series of curves shows the electromotive force acting in circuit (5), that is, in the transmission line, as the transmitter brushes are adjusted.

The numbers opposite each figure indicate the phase of displacement of the transmitter brushes from the position they occupy when the commutator reverses the circuits.

The commutator brushes are in the normal position.

The heavy line, as in previous diagrams, denotes the part of the curves which is transmitted through brush circuit (3), and the dotted line through brush (4).

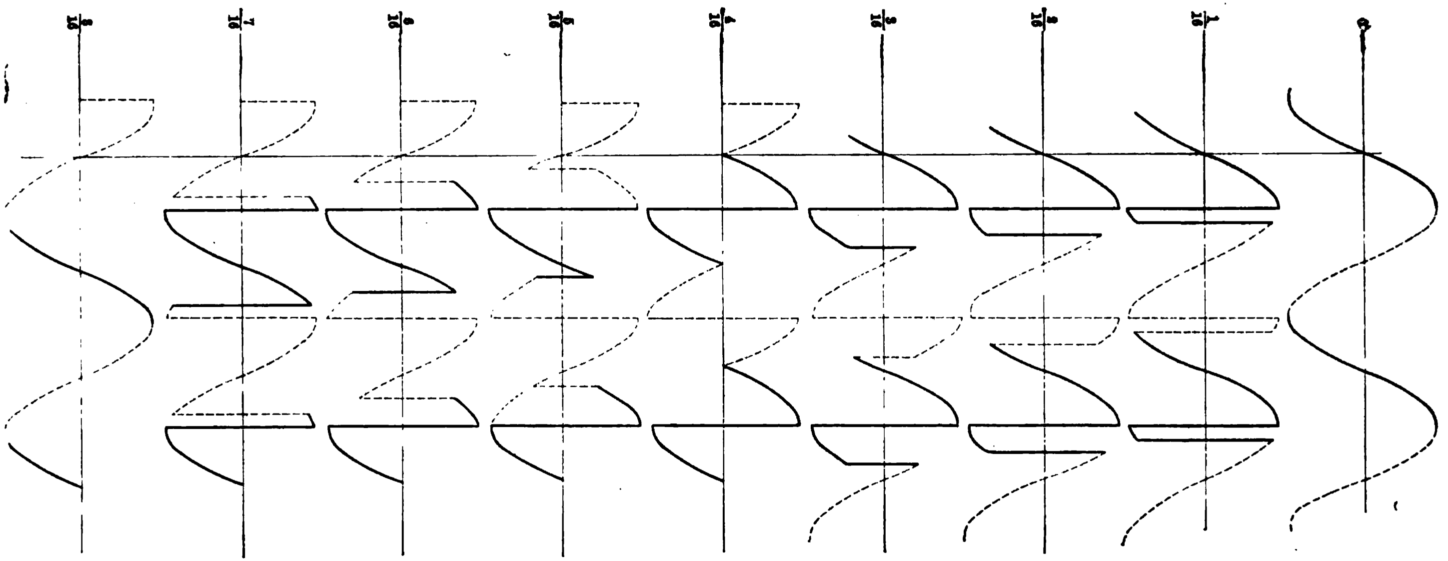


FIG. 31.—Commutator brushes $\frac{1}{8}$ revolution from neutral point.

The series of nine curves represents the electromotive force acting in circuit (5), that is, the transmission line, as the transmitter brushes are adjusted.

The commutator brushes are fixed at one-eighth of a revolution from the neutral point.

The numbers opposite each curve give the phase of displacement of the transmitter brushes from the position they occupy when the commutator reverses the circuits.

The heavy line denotes the portions of the curves where the electromotive force is transmitted through brush circuit (3) and the dotted line through circuit (4).

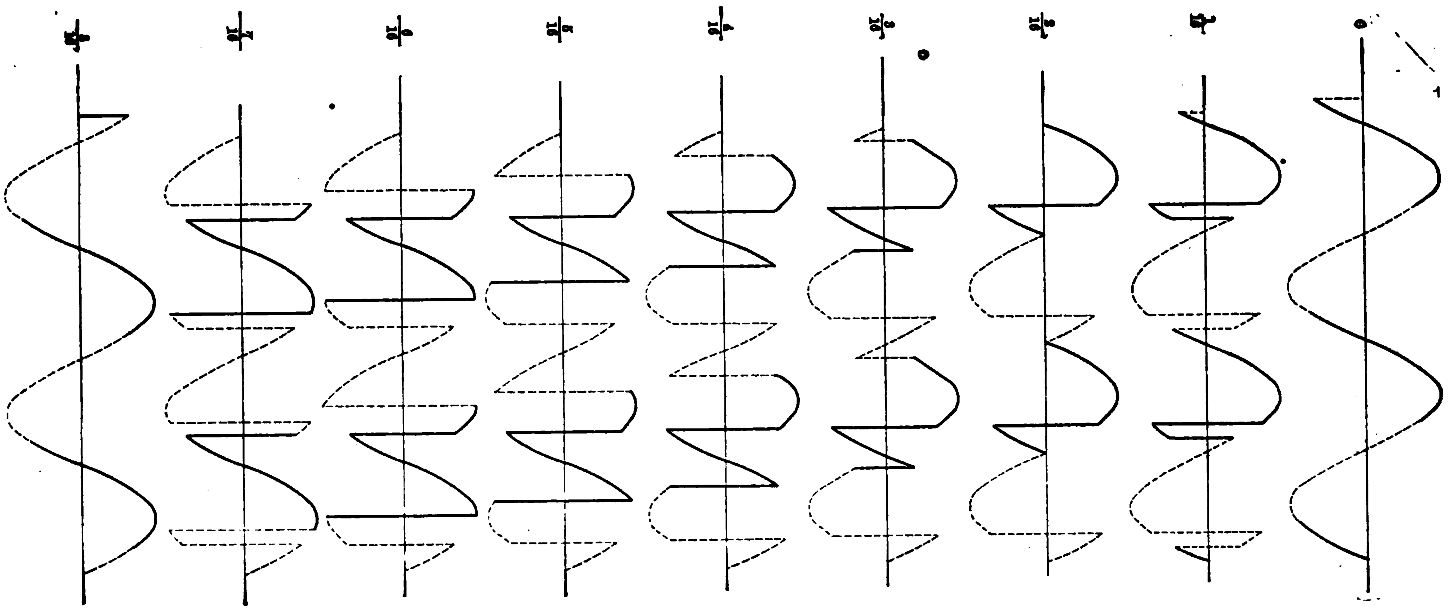


FIG. 32.—Commutator brushes ¼ revolution from neutral point.

The series of nine curves represents the electromotive force acting in circuit (5), that is, the transmission line, as the transmitter brushes are adjusted.

The commutator brushes are fixed at one-quarter of a revolution from neutral point.

The numbers opposite each curve give the phase of displacement of the transmitter brushes from the position they occupy when the commutator reverses the circuits.

The heavy line denotes the portions of the curves where the electromotive force is transmitted through one-brush circuit (3), and the dotted line through circuit (4).

Fig. 33.—Zero Phase. Siphon record corresponding to Fig. 30.

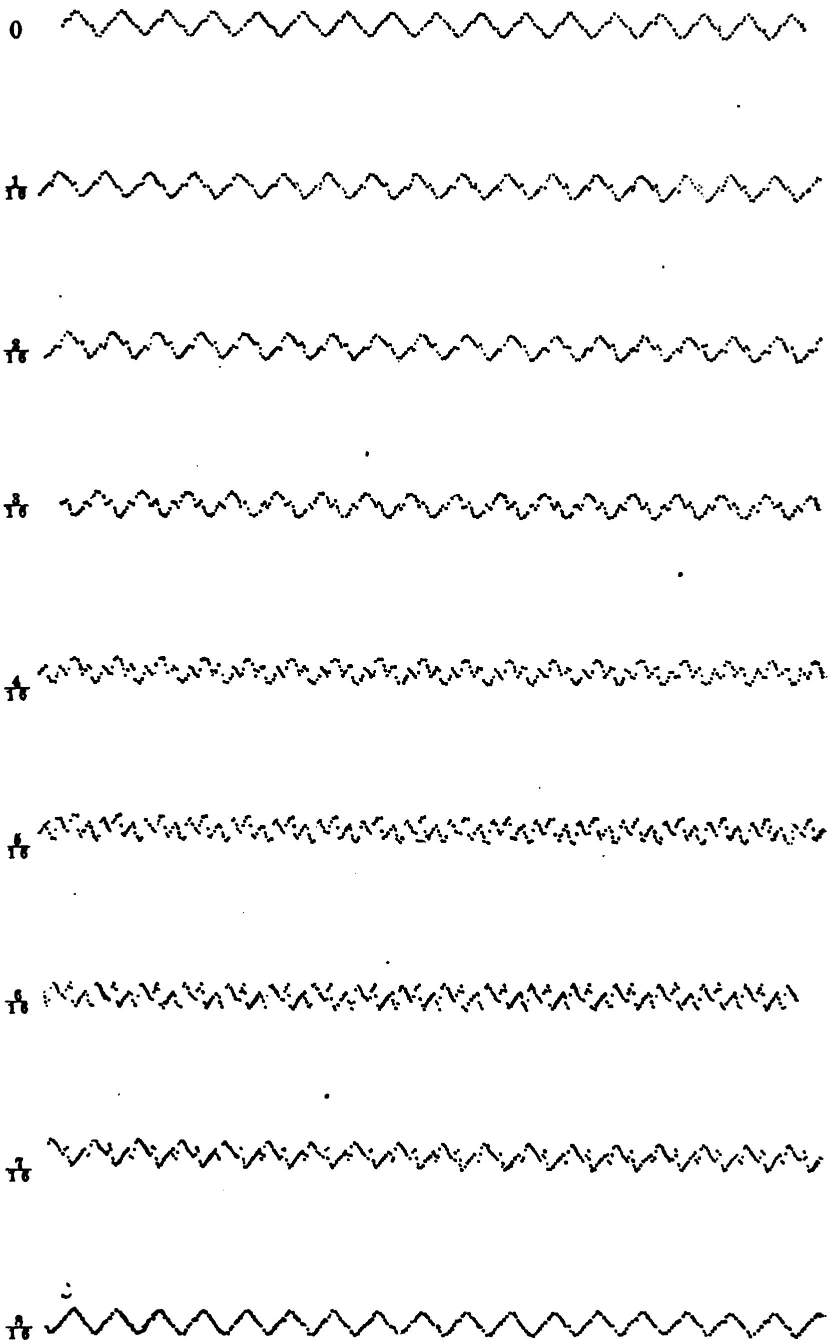


Fig. 34.—⅛th Phase. Siphon record corresponding to Fig. 13.

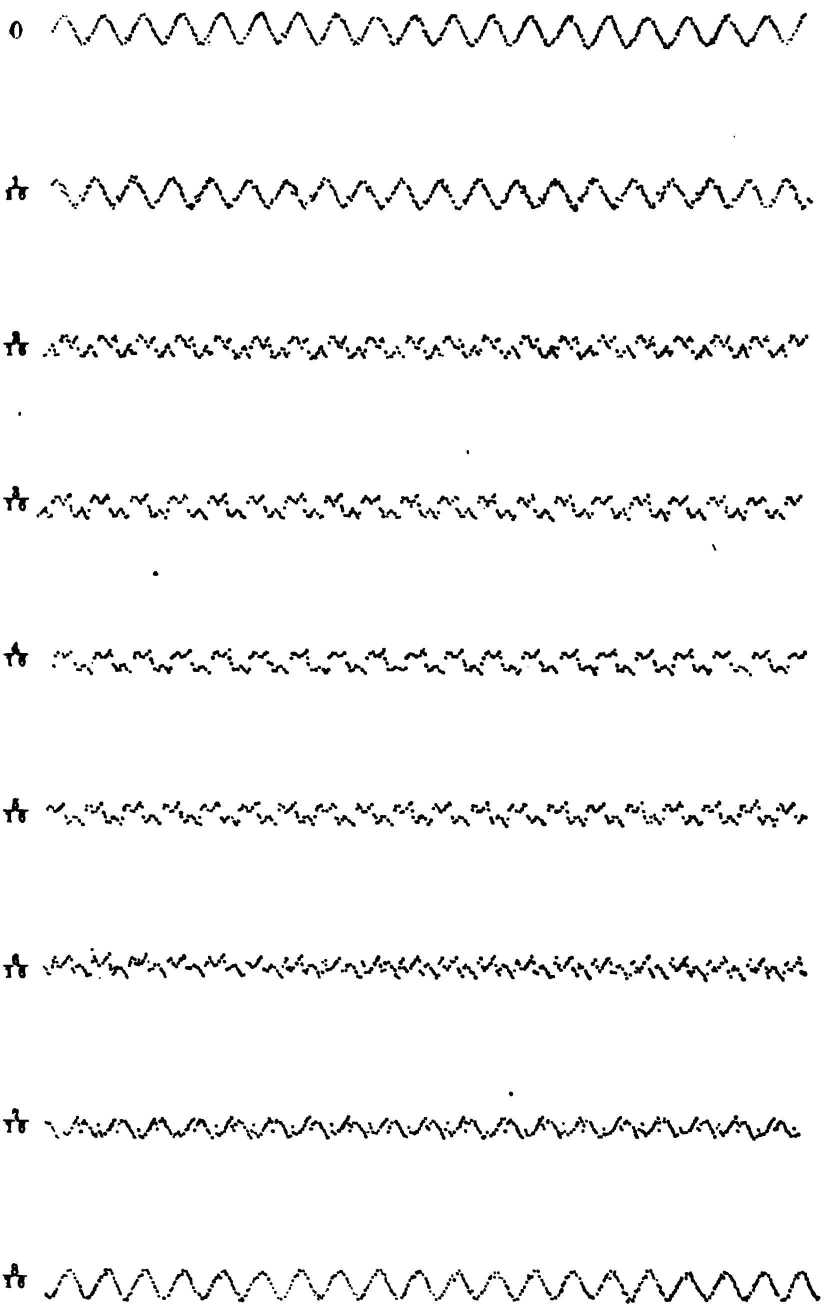


FIG. 85.—¼th Phase. Siphon record corresponding to Fig. 83.

Discussion.

Dr. Crehore:—Mr. President, please allow me one word in explanation of the point that Captain Squier makes. The fact that we have some letters that require successive signals in the same direction makes it easy to read if they occur in a certain order. Expert readers can easily pick out an *h* if it is isolated; but if you had a succession of *h's* or a succession of small *h's*, which is three dots, there is only earth in between; or if, for instance, three *c's* come out at the other end by a large alternating current, it makes a large record. If you had *s s* you would not get the separation between them that you would between *s o*, which is very easy to read. The point is that you have these bad letters, which are liable to occur in a succession and which you cannot easily read.

Dr. M. I. Pupin:—I am very glad that Captain Squier and Dr. Crehore have brought up this subject, before the Institute. It is an interesting subject, and has been worked out by them very carefully indeed. We have all heard that a long submarine cable on account of its capacity, is a very slow thing, and whenever we mention an Atlantic cable we also associate with it a certain amount of slowness. As a matter of fact I should think an Atlantic cable rather fast, because anything which is capable of *dissipating* as much as the Atlantic cable cannot be called very slow. Owing to the rapid increase of the attenuation constant with the frequency we have the infallible result that no matter how complex the current is which is sent in at one end, you are going to get at the other end its fundamental only. In other words, the amount of integral current that you send at one end of a cable will be in no definite relation to the amount of integral current that you receive at the other end. There will be a definite relation between these two amounts, if you consider the fundamental of the wave sent in. In other words, again, the wave energy which accompanies the fundamental is the available energy. That is the energy which goes through. The wave energy accompanying the upper harmonics is not the available energy. The wave energy accompanying the integral current sent into a cable behaves something like heat; and you might say there is such a thing as an entropy connected with it. Now what these gentlemen propose to do—and the proposition is an excellent one—is to get electrical energy sent, in which there is as large an amount of available wave energy as possible. There are two distinct advantages in that. In the first place, with a given impressed electromotive force at one end you can put a great deal more of available energy into the cable, and also with a great deal less of integral current than you would with a complex harmonic electromotive force. What does this bring about? The current sent in is smaller than when you use a complex harmonic, and that seems to be a clean cut advantage. I do not think there is any doubt in anybody's mind, who has listened to the paper, as to the strength of their argument and as to the strength of their position.

The second excellent element in connection with this paper is that we have here, as far as I know, the first scientific measurement of the alternating current elements which come into consideration when an alternating electromotive force is applied to a cable. I have often thought myself, how large a current it would be necessary to put in at the sending end in order to get enough at the receiving end of a certain line, to work the siphon recorder—a siphon recorder as sensitive as the ordinary one. To be sure, we can sit down and make that calculation if we know the impedance of the cable for a given frequency, but it is always more encouraging to have actual experimental measurements, which Capt. Squier and Dr. Crehore have made. So that taking these two considerations into account, the one not only purely scientific but also a practical consideration, and the other a purely scientific consideration, I think that on the whole we can congratulate ourselves that these gentlemen have taken the trouble to prepare this careful paper and to have it embodied in our TRANSACTIONS.

MR. P. B. DELANY:—I want to make a few remarks in regard to the paper which has been read, and if any thing that I may say does not show reasonable familiarity with the merits of the paper I do not think it should be charged entirely to me, for unfortunately, I have not had a chance to study, or even read it, owing to the fact that there was some failure in the distribution, or delay in its preparation on the part of the gentlemen themselves, so that it was not available. I would like to make a few observations from a practical standpoint, and based upon what Dr. Crehore and Captain Squier have explained in reviewing the paper. It would appear that the efficiency of the ordinary transmitter as drawn by Dr. Crehore on the board, was taken as standard, regardless of its mechanical construction. I have found by experiments, that the speed in transmitting signals depends very largely upon the duration of the contact—I am now speaking of ordinary cables—between the battery and the cable itself, or through the condenser; and that while at the apex of the cable the electromotive force rises, we will say, to its highest point, I do not think this makes much difference, as every wave is sinusoidal at the receiving end of the cable. In an experiment made a few years ago between Ireland and, I will say, this side, a trial was made of two transmitters, one being the ordinary Wheatstone modification shown by Dr Crehore. Without any change from the usual adjustment, the speed for regular signals was ascertained to be 188 letters per minute. The cable was then transferred to the other transmitter, having different kind of contacts for applying impulses to the cable. The speed at the starting point was 207 letters per minute. That rate was taken at a guess and counted afterwards for verification. The arrangement for the trial was that the operator at the receiving end should make such observations regarding the character of the work as his judgment should dictate. At the first trial after the change of transmitters, at a speed of 207 letters, his remarks were, "Those signals are o. K, but too large. I will shunt my receiver and draw out the magnets"—it was an adjustable field —with a view of course of reducing the amplitude of the signals. He was told not to do that, but leave his magnets as they were, and to increase the tension of the adjustment of the suspended coil, to which is attached the siphon, and take advantage of the increased power as indicated by the greater amplitude of the signals for quicker return of the coil to the neutral point. His reply after receiving these instructions was, "All right. I will do as you say." The speed was then increased to 222 letters a minute, and his reply was, "Those are o. K."

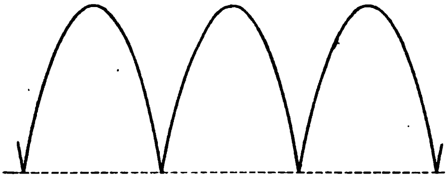
Then he was asked if they were good enough for traffic. He said, "Yes, they are good enough for traffic"—which is always a crucial test in regard to cable signals. Then the cable was put back to the original transmitter, making shorter contacts, and he said "Those are all there, but infinitesimal. Will you increase the battery or shall I slacken the adjustment?" He was told, as these gentlemen have pointed out, that they could not increase battery power, but he must do everything that he could to break down the discrepancy between the two transmitters, and after some adjustment he got back to the original speed, 188 letters a minute, and said that they were "fair for traffic." There was a vast difference in the construction of the two transmitters in the point of duration of the contact between the battery and the line, one being the Wheatstone—the ordinary modification of the Wheatstone transmitter, where the rods are worked by a walking-beam, making the contact on passing through the holes, and the other being a scraping contact, with brushes above the paper and brushes below, the duration of contact being altogether dependent upon the size of the holes in the tape, whereas in the other case of course it would make no difference about the size of the hole, so long as it was sufficient to admit the point. It has been observed here, and it has long been well known, that with an alternating wave, not irregular, but with uninterrupted succession, you can get a greater number of waves in given time than in any other way. I find on land lines, with chemical recording, that the regular make and break alternations, without any attempt at breaking the circuit at the zero point—will give a record at a speed three times greater, and with perfect distinctness, than where the impulses are sent successively from the same current. As Captain Squier has observed, the definition cuts very little figure in the reading of cable signals. Unless the speed is very slow, or the cable very short, or the capacity very low, the definition will not be such as to form a basis to guide the operator. In the cross letters of course, even with ordinary reversals, there is a margin of speed very much greater than would be admitted by the inherent difficulties in the formation of letters where successive signals are sent. Therefore the advantages of a sine wave for the cross letters are not necessary, because the ordinary reversal gives definition to a degree far in excess of the speed admitted by the other letters. The mere fact, of finding it necessary to put the cable to earth after each letter, shows I think, that the claim made some time ago that breaking the circuit at the zero point eliminated difficulties arising from retardation caused by electro-static capacity, has not been realized in practice. If it is found advantageous to discharge the cable between the letters, I think it is quite evident that a definition, such as might be expected, is not gained in long cables by the mere fact of the voltage declining to a zero point, at which it is broken. The paper has great interest and has done a great service, I think, in arriving at some scientific data with regard to the signaling capacity of a cable. I for one appreciate very much what these gentlemen have done, and if their theoretical premises are correct with regard to the gain in the speed of cables over other methods. although nothing appears in the paper to show the difference in actual transmission, I for one shall be very glad to recognize it.

DR. FREDERICK BEDELL:—We have had presented a paper on a subject of much importance, which should be carefully considered and discussed from various standpoints. In using an alternating current in the manner described certain advantages have been gained, and it is proper to inquire what are the limitations and what are the possibilities in cable telegraphy, and whether advances are to be made in this direction, or in a different one.

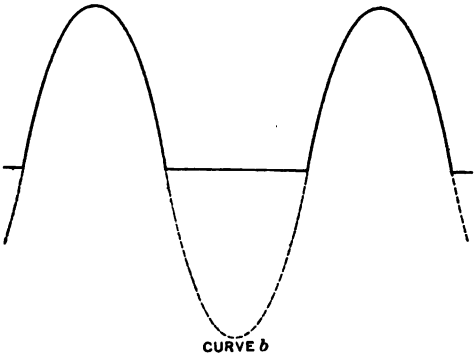
The advantages of a sinusoidal wave for the transmission of current, whether it be for power or for other purposes, have long been recognized by engineers. So weighty are the arguments in favor of such a wave that the matter might be considered almost beyond controversy. Accepting then an undulatory or sinusoidal wave as being desirable for telegraphic as well as for power transmission, let us consider the features involved in its use.

In substituting a more or less sinusoidal alternating wave-form for impulses of the crude rectangular type, the corners of the impulses are rounded off and reactive disturbances avoided to a corresponding extent. This feature of the avoidance of sharp corners is a matter of very great importance in any system of telegraphy, be it alternating or direct. It is to be borne in mind, however, that the maximum reaction in an alternating current occurs at the zero point, and it is at just this point that the authors of this paper operate. With a rectified alternating current this effect is even greater, as will be obvious from an inspection of curve *a*. The sharp corners have been rounded off at the crest of the wave, but have been intensified so as to form a sharp point at the trough, the resultant wave being now far from sinusoidal. The code suppression of a semi-cycle still leaves a corner, as in curve *b*. But even with these defects the use of an alternating current is, as the authors show, an improvement on the usual practice, on account of the rounded corners at the crest.

Let us consider the effect of this sharp reactive point. In the apparatus which has just been described to us, two alternating electromotive forces are generated, of opposite polarity, and with coincident zero and maximum points; that is, electromotive force A is negative when electromotive force B is positive; then B is negative, while A is positive, etc. In the tape transmission, the cable is connected either to A or to B according to a code.



CURVE *a*



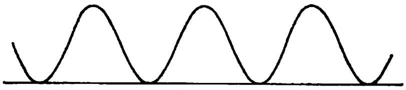
CURVE *b*

The condition of the cable so far as stress is concerned may, perhaps, be more readily understood by considering two synchronous swings, one to represent electromotive force A and one to represent electromotive force B. These swings pass each other at the zero position when at a maximum velocity. Now imagine a passenger transferring himself from one swing to the other as they pass. It is true that the two swings are at the zero point at the time of transfer, this being the position which they would both have if at rest, but they are moving in opposite directions and at the maximum velocity. With the alternating current transmitter that has been shown to us, has not the cable the somewhat uncomfortable task of the passenger in his transfer between the swings? We know that the passenger would be subject to physical stress as well as to mental strain. Is not the cable subjected to a similar stress? Would not its life be lengthened if this reaction could be avoided?

I have had occasion to do some work in the transmission of direct current impulses and am led to believe that a wave-form, as that shown in curve *c*, possesses many advantages. This is a direct current, of sinusoidal wave-form, without reactive points. The electromotive force rises gradually from zero and descends gradually, so as to be more or less tangent to the zero line. I have found that such direct current impulses may be satisfactorily produced by a continuously operated graduated rheostat interposed between the battery and the line.

By this means the line may be given a periodically increasing and decreasing potential, as the sine-wave in curve *c*. By properly grading the resistances, any desired wave form may be obtained to suit the conditions of service.

The apparatus may be readily constructed so as to give a double series of direct current impulses, one positive and one negative.



CURVE C

Now when the cable is connected sometimes to electromotive force A and sometimes to B, according to a code, the change is made at the time of minimum reaction, and reactive disturbance is practically eliminated.

If we consider two swings to swing so that they just meet but do not pass each other, our passenger could transfer from one swing to the other without inconvenience. Any possible code selection of impulses from A or B can not introduce a sharp point in the resultant curve, the transition being always gradual, a feature conducive to higher speed, higher permissible voltage, and (what must not be overlooked) a lessened liability to interruption and greater life of the cable.

There is one point of consideration in the matter of electrostatic hysteresis which is of physical interest. Its effect is such —either to a greater or less degree—that electromotive force and current cannot both be exactly harmonic. This is well recognized with ferric hysteresis, and the same is true when we have a capacity with an electro-static hysteresis loop.[1] The effect of such hysteresis is that to obtain a true sinusoidal current, the electromotive force must be adjusted so as to deviate to a certain extent from a sine-wave.

---

[1] Such a loop obtained by the speaker with others is given in the TRANSACTIONS, page 585, vol. X.

In regard to the matter of equivalent voltage of a sinusoidal wave and any other, I would be inclined to take a position even more favorable to the sine wave than have the authors of this paper, who say that a sine wave with virtual voltage of 35 is equivalent to a battery voltage of 50, applied either directly or through a condenser. On account of the easy application and withdrawal of an undulatory electromotive force, I am inclined to believe we are nearer the truth if we take its virtual value as its true measure, and say that a sine or undulatory wave, either direct or alternating, with a virtual value of 50, as measured in any usual way, is equivalent to a battery voltage of 50 applied with full initial value without gradation.

In closing I beg to express my very high appreciation of the paper to which we have listened and to repeat my advocacy of a sinusoidal or undulatory wave and to call attention to the reactive disturbances which have been mentioned.

DR. CREHORE:—Mr. President, I want to take this opportunity of speaking on a special point raised by Dr. Bedell, and give the views as they appear to me, illustrating them by the diagram. It must be borne in mind that there are few kinds of letters in cable signaling; what we call the cross letters and letters that have signals in the same direction. It is almost impossible, at least I do not see how it is practical at the present time, to employ sine waves strictly for both kinds of letters. If you are going to use sine waves at all you should take the choice which kind of letters you will have the true sine waves operate, and I think it is most important to have the cross letters with the sine wave. Dr. Bedell's method uses the sine wave for the letters which are not cross letters, but does not use the sine wave for the cross letters. Allow me to redraw the curve. This (making diagram) being the zero axle, the letter A could consist of *this*, followed by *that*. The simple reversals would be, coming down here to the tangent. Now in no sense can we consider that a sine wave for sending impulses through the cable. The effect of such a wave as that would be equivalent in operating the receiver at the other end, through a motor sine wave. In other words, I anticipate that if such a wave as either of those two were tried you would get just the same result at the other end of the cable. You have to use a higher voltage in connection with Dr. Bedell's proposal than you do with a true sine wave. The sine wave which is proposed is double the frequency of the sine wave which we use. If you are working at a period of 5, which is a normal working period, therefore the other wave must have a frequency of ten. Though you send that sine wave directly into the cable, without having a direct current, or even if it is a direct current, at the other end you cannot see anything but a slight tremor, if you see that. In other words, having the recorder in the series, and sending in like *that*, you get practically the same thing. It will start up there and go down to the zero line, because the condenser at the other end stops all current and you only get the pulsations after a while. Therefore it is unimportant what shape of curve these successive portions have for a given letter. For this reason if you send the first one alone and then allow the cable to be insulated until you care to send a reversal in, or the earth, the record is good at the other end. When you apply a battery to our brushes that is what happens. To illustrate by a particular case take the letter B. We have holes in the paper like *that*,—a dash and three dots. The brushes *here* make continuous contact there from beginning to end. If you apply a battery on these impulses you will find you get a negative impulse and then a positive impulse, which stops the current, and it remains stopped until you come to the end. We find that method gives good signals. They look better than they do to put anything in separately for these successive ones after the first. And I am very desirous of making a perforator which will send *these* signals. These holes represent A. (Illustrating). You will get a better record at the other end by doing that than you will by retaining these other impulses. C is a dash, dot, dash, dot. If a perforator is going to strike the hole in the upper line for a dot and a hole in the lower line for a dash and then one on the lower line for a space, it is difficult to do it with these feed-holes alone, since you have a punch which requires the operator to learn a different method. Of course a letter perforator, which is the coming kind of perforator to use, will easily overcome that difficulty and I hope we can experiment with such a plan as that. The point then of objection to this is that it has double the frequency of the sine wave and does not apply the sine wave to the most important case that exists; and it requires a higher voltage.

PROF. FRANKLIN:—Mr. President, when I listened to Dr. Bedell's suggestion it struck me at first as a very reasonable one. I have since thought, however, of one or two of the points mentioned by Dr. Crehore, and it occurs to me that there is one other thing in Dr. Bedell's suggestion which is not altogether rational, and that is that he loses sight of the fact that the circuit is only broken when the current is zero. That is, the velocity of zero is an analogy of the two breaks. It would not apply in that case because the scheme only anticipates breaking the current when the circuit is at zero and has an adjustment in the machine for actually reaching that condition.

MR. C. P. STEINMETZ:—Mr. President, I have listened to the paper with very great interest, and consider it as one of the most important contributions, illustrating the investigation undertaken by the writers of the paper and continued now for several years. Considering that telegraphy is one of the oldest things in electrical engineering, and has made enormous strides in the last part of the century, it is remarkable that almost no attention has been given to the generating part of the power used in telegraphing.

Since an early day the same power has been used for make and break, and no attention has been given to a scientific investigation of the problem of generating power for telegraphy. The first investigation that I know of are these investigations of Dr. Crehore and Capt. Squier, and I think the results derived from them are of extreme importance. When the first paper was brought out by these gentlemen it struck me as showing the importance of using the sine wave. The same thought struck me which was referred to by Dr. Bedell to-day. In reality they do not use a sine wave, as I understand, but half a wave followed by a space. They do not use a complete wave. Now half a wave is not a sine wave. If you use the two half waves here—(illustrating by diagram on the board) it should be first said in the investigation that in a cable it is separated from the condenser. The change of electromotive force is the only thing that is important. What you really get by an adjacent wave of the same direction is the alternating current of greater frequency; and the positive part of the wave being rounded and the negative part being sharp, such a wave should be expected to work in a cable like this. The effect of using the half sine wave is a change to the double frequency, and a reduction of the effective value of the electromotive force. Now we have this cable acted upon by two frequencies and two electromotive forces. In frequency the upper signals follow each other with full electromotive force and the sub-frequency descends, which acts like such a wave—(illustrating) that is a wave of double frequency and effective value less than half the other one. ' Looking at this it should be expected that the most important of those high frequency waves was a higher electromotive force than the sine wave, because this wave can take care of itself and will smooth out, and that is still higher than the effective value of this distorted wave. That should be expected. I believe this wave proposed by Dr. Bedell would be preferable. This wave can be produced very easily by a machine. For instance, take a machine with a collector ring to one point of the armature, and then with a controller ring to one part of the commutator brushes and you get it this way. (Illustrating) It seems from Dr. Crehore's statement that experience does not agree with his theoretical reasoning, and the reason is something which I have not foreseen, and which I do not think could be foreseen by anybody who has not especially studied the thing radically; and that is that you really do not use these successive half waves as an electromotive force. You have successive half waves in the same direction, but there is not a sine wave, but a steady electromotive force; and in this case where you want a steady electromotive force the wave shape is immaterial. All you want is the maximum quantity of electromotive force, and the larger quantity you get by the sine wave rather than by this pulsating sine wave. That probably is the reason why the sine wave is preferable for the lower frequency only and the wave shape in general is immaterial, because what we get then is a constant electromotive force.

Mr. Hammer:—Mr. President, I would like to ask Mr. Delany, Dr. Crehore, and Capt. Squier, one practical question, which it would be desirable to get on the record, if these gentlemen have no objections, and that is the maximum speed that they obtained under commercial conditions. It may be desirable to explain the circumstances under which that maximum speed is attained.

Capt. Squier:—Mr. President and gentlemen, I can say that practically the same apparatus has been in actual traffic use on an Atlantic cable for several days at a time, during its development, in the last two years, and we are largely indebted to that actual practice. There are many things undoubtedly still to be determined which can only be determined by the test of actual traffic. When we come to speed, it is a difficult matter to state any way. They use one speed for traffic, where they require code words, which is a large per centage of the traffic now, such as the stock market, and have to use a slower speed. All I can say is we make a material gain in speed all along the line, for an equivalent voltage; but to state the exact amount would be impossible, because it depends on the particular cable, and the staff at the ends. A great deal depends on the people using the cable. Some men can read almost anything; they can almost read straight lines, they are so expert. So the whole matter is rather a difficult one to state, and if we state a gain in per cent. we have to explain how and under what conditions. So I only say in general it has proved more effective than any other wave we have employed. We have three books of sample signals here, which are open to any of you, and you can make a comparison for yourselves.

Dr. Kennelly:—Mr. President and gentlemen, we have had a theory of alternating current transmission as applied to submarine cables ever since Lord Kelvin's classical work upon that subject, prior to 1865; but I venture to say that we have had no practice, or practical knowledge, with a check upon the reliability of that theory, in published form until today. The importance of this paper it is difficult to overestimate, on account of the great value it may have from a practical standpoint, and on account of the still greater value it must inevitably have upon the engineering advance in this direction. During the last fifteen years very little progress has been made in the direction of increasing the speed upon long submarine cables. On short cables no one cares about the matter. You can put down any piece of wire in a cable, and insulate it well, and so long as it is time-constant, that is to say, so long as the product of its ohms and farads does not exceed one second—you multiply the number of farads by the number of ohms and get the product in seconds, and so long as you do not exceed one second, if you have a short cable, you can work it any way you choose, but when you take a long cable, the time-constant goes up as the square of the length, the core remaining the same. When you come to five and six seconds, such as the Atlantic cables have, you have to apply the most refined means known to engineers in order to obtain commercial rates for the cable, and an advance of ten per cent. in the rate of signals is a material gain; material financially, because it means that you can employ a smaller core, less gutta percha, and less copper; material from a traffic point of view, because with a given cable once laid, you can send more words through it per minute. All this has been known and reduced to practice for ordinary rectangular wave, battery transmitters; but we have not till to-day had available measurements for alternating current transmitters. Looking upon the matter from an engineering standpoint, as these gentlemen have done, considering that you have a motor at the distant end of a long cable and that you have an alternator at the generating end, then it goes without saying that the sine wave method of transmission must be right. I think that will be a self-evident proposition, as soon as you consider it carefully. If you were to apply an ordinary current wattmeter at Ireland and transmit in to the generator in Canada a given amount of power in watts by the rectangular wave, that is, by the sinusoidal wave, the same amount of power transmitted in the two cases would show much greater received power in Ireland for the sinusoidal wave than it would for the rectangular wave. Considered from the engineering standpoint of the transmission of energy, all the harmonics in the rectangular wave represent waste power.

So far we are dealing with the supposition that you are going to take power out at the receiving end; and that is not practically true, because you do not have a wattmeter in Ireland; you have a delicate instrument which requires about 30 microamperes of current to operate it, and is not the same as a wattmeter. Moreover one does not send a sequence of reversals. The impulses sometimes alternate, and sometimes are successively similar. Therefore it is necessary to introduce some modification in the case and change from the pure case of the transmission of energy to the case of the transmission of intelligence from the wattmeter, which knows no distinction of persons, to the eye which has to be trained to read these signals. As Capt. Squier clearly expressed it, you can find one man who will read those signals and will be able to receive the current at a certain frequency, and another man may not be able to do it. The result is that although it is absolutely certain that the sine wave transmission must be much better than ordinary rectangular transmission for power to a motor or wattmeter, the disproportion is probably not so great, when you come to mixed signals to a siphon recorder. Undoubtedly there must be an improvement. The sine wave with the omission of all the harmonics must have a distinct advantage; but the advantage ought not to be as great when dealing with a siphon recorder as they would be if you simply had a motor. You have a mixed problem there and it is impossible to get accurate results until you have some machine which will read and decipher standard signals. But there can be no doubt that even if this system were not introduced into practice, we owe much to the authors for the clear and scientific way in which they have presented their results.

MR. DELANY:--Mr. President, in regard to the inquiry relating to speed over the Atlantic cable; as Capt. Squier has pointed out it is a very wide question, depending very largely upon the cable and its insulation and its resistance, and also to a certain extent on the people who are operating it, although there is a standard of safety in cable telegraphy which holds it down to the abilities of any man in the office who is permitted to work the cable. The signals must be plain enough for every man in the office to decipher them, and the speed of the machine, as matter of fact, is independent of the receiver; the speed of the cable is independent of the receiver except to the extent that the receiver is supposed to translate the signals as fast as the machine will produce them, although the machine may run ahead of the man who is transcribing, and of course at the transmitting end, which is worked by machinery, the speed has nothing to do with the operator. Over the 1873, 1874 and 1880 cables of the Anglo-American Company, for instance, the speed does not vary very much. The highest signaling over the 1894 cable that I am aware of, with regular traffic in the middle of the day, has reached 252 letters, or 50 words per minute, with the traffic just as it came; and no cable traffic is easy except perhaps a newspaper report.

PROF. OWENS:—Mr. President, I have had the fortune of seeing something of this apparatus, and I wish to say that I also appreciate the presentation of the paper here. I think it can be clearly seen that the authors have demonstrated the advantages of the sine wave. Why the alternating current has not long ago been applied to the transmission of energy for distributing intelligence, I fail to see. One of the most interesting points in the cable, to me, is the apparently established direct line of relation between speed and electromotive force. The second important point is the advantage of the sine wave over a battery wave of the same maximum amount. If nothing more than these two points were proven, as they seem to be, I should consider the paper of extreme benefit. The apparatus as such is very perfect and it alone would seem to be a great advance as far as I am familiar with the subject. We are indebted to the authors for presenting the result of their work here.

[COMMUNICATED AFTER ADJOURNMENT BY DR. BEDELL.]

A point has been well brought out by Dr. Crehore in regard to code, and that is the matter of good and bad letters. The former are cross letters and the latter are letters that have signals in the same direction. The fact has also been pointed out by Mr. Delany that it is generally found that the speed is restricted not by the cross letters but by the bad letters with successive impulses in one direction. In my remarks, a wave-form coming gradually to zero was indicated which would help these bad letters. The variation being always sinusoidal, it is likewise well adapted to the cross letters; but the greatest advantage comes in the bad letters by avoiding such bad effects as accompany the sharp reactive point which occurs between successive impulses of one direction, obtained from a rectified alternating current.

I may add that from the fact that a higher voltage may be permissible with sinusoidal direct current impulses, on account of reduction in the strain upon the cable, resulting from the elimination of sudden inductive reactions, it does not follow that a higher voltage is necessary when such impulses are employed.

With reference to the remarks made by Dr. Crehore, that sinusoidal impulses of one polarity (curve *c*) may be considered as waves of double frequency, Mr. Steinmetz has clearly shown that a rectified alternating current gives a series of impulses of double frequency which are non-sinusoidal, so that only their fundamental harmonic is available and the effective value is much reduced from what it would be were the waves sinusoidal. It may be that no one fixed wave-form will possess all the virtues and be the best for every letter and every code, but we may study the difficulties and minimize the weak points and accentuate the strong, adapting our wave-form to meet the conditions.

THE PRESIDENT:—If there is no further discussion the Committee on Resolutions is ready to report. I will ask the Chairman to read the resolutions.

The Chairman of the Committee, Mr. Calvin W. Rice, presented the following resolutions:

MR. PRESIDENT:—In accordance with the motion of Mr. Dunn, and the action of this meeting, we, the Committee appointed by you to propose such resolutions as will fittingly acknowledge the courtesies and hospitality, received at the hands of the Philadelphia Reception Committee, and our brethren in Philadelphia in general, do hereby report, and present for your consideration and adoption the following expressions of appreciation.

RESOLVED:—That we hereby express to the members of the Philadelphia Local Committee, to the members of the Institute in Philadelphia, the Franklin Institute, to the Trustees of the Drexel Institute, the Morelton Club, the Manufacturers' Club, the William Cramp & Sons Ship and Engine Building Co., the Baldwin Locomotive Works, and to such other Corporations as have given us the freedom of their establishments and contributed to our entertainment, and to all other to whom we are indebted, our sincere appreciation of and thanks for the many courtesies they have on every hand extended. These courtesies and hospitality but uphold the tradition of the city of our hosts for the kindness of its welcome. And be it further

RESOLVED :—That these resolutions be spread upon the records of our society, and suitable copies be sent to the Chairmen of the Committees and the representatives of those whose invitations it has been our pleasure to receive.

CALVIN W. RICE,
GEORGE F. SEVER,
W. W. KER.

MR. DUNN:—Mr. President, I move the adoptions of these resolutions by a rising vote.

THE SECRETARY:—Before the vote is taken I would suggest that the resolution be subject to amendment by the insertion of certain names that may have been omitted by inadvertence, in order to make it complete.

MR. RICE:—I accept the amendment.

Seconded and carried.

THE PRESIDENT:—The next paper will be "Telephony over Cables and Long Distance Air Lines," by Dr. M. I. Pupin.

A paper read at the 17th General Meeting of the American Institute of Electrical Engineers, Philadelphia, May 19th, 1900, President Hering in the Chair.

WAVE TRANSMISSION OVER NON-UNIFORM CABLES AND LONG-DISTANCE AIR-LINES.

BY M. I. PUPIN, PH. D.

This paper describes an experimental investigation of a method of constructing cables and long-distance air-lines for power transmission by electrical waves, particularly for long-distance telephony and telegraphy. This method is a practical application which offers an experimental test of the general mathematical theory of wave-propagation over non-uniform conductors, which is given in the second part of the paper. The first part contains a physical explanation of this mathematical theory and a description of experimental researches bearing upon it. It also describes an experimental verification of long-distance telephony over non uniform cables.

Physical Theory of Electrical Wave-Propagation over Cables and Long-Distance Air-Lines.

A. *Wave Propagation Over Uniform Conductors.*—Transmission of electrical energy over conducting wires is a *wave transmission* when the distance between the transmitting and the receiving apparatus is sufficiently long to permit the development of electrical waves. Such a transmission exists in long-distance telegraphy and telephony. It does not exist to any practically appreciable extent in ordinary transmissions of electrical power by alternating currents over distances which up to the present time have been bridged over by electrical power transmission lines. In cases of wave transmission considered here the conductors will be called *wave conductors.* The circumstances attending wave transmission are considerably different from those attending ordinary electrical transmission and should be carefully differentiated from them. In ordinary transmission the reactions set up in the receiving apparatus are the most essential reactions which the force impressed by the transmitting generator has to overcome. The reactions set up in the transmitting line itself are small in comparison to it. The case is analogous to the transmission of power from the piston of a steam engine to a motor connected to the engine by a short, stiff, piston rod. The reactions set up in the piston rod itself are small in comparison to the reactions which the motor opposes to the driving pressure. Hence, neither the elastic nor the kinetic reactions of the piston rod, nor the reactions due to internal frictional resistances in the rod are seriously thought of when we analyze the reactions attending this case of power transmission. But consider now what will happen if we increase the distance between the piston and the receiving motor and consequently increase the length of the piston rod. We can no longer consider the rod as a perfectly rigid connection between the driving pressure of the piston and the reactions of the receiving motor. The rate at which the piston delivers energy at any moment is not equal to the rate at which energy is delivered at the receiving motor at that moment. There is a lag in phase. The energy transmitted is first stored up in the piston rod and then delivered from the rod to the receiving motor. While it is stored up in the rod it exists partly as kinetic energy of the moving mass of the rod and partly as potential energy, due to the rod's elastic deformations. The process of transmission consists in successive transformations of the kinetic into the potential energy of the rod and vice versa. These transformations being progressive the energy is propagated along the rod, and we say that the propagation is a wave propagation, in order to state in a single word that the progressive motion along the rod is a periodic one. Analogous conditions exist when electrical energy is transmitted by a periodically varying electromotive force acting on a long conductor. The transmission is not a direct one; the transmitted energy is first stored up in the medium surrounding the transmission line, and from there it is transferred to the receiving apparatus. While it is stored up in the medium it exists there partly as magnetic energy stored up in the field of magnetic flux and partly as electrical energy stored up in the field of electrical flux. The process of propagation consists in the progressive transformation of the magnetic into the electrical energy and vice versa. When the electromotive force impressed by the transmitting generator is a periodic one the propagation will be in the form of electrical waves. The expression "electrical wave" is nothing more nor less than a brief statement of the physical fact that in the case under consideration the energy which at any moment is stored up in the medium surrounding the transmission line is distributed periodically over this line. The current and the potential also vary periodically. At points of maximum magnetic energy the current is maximum, and at points of maximum electrical energy the potential is maximum. Roughly speaking, points of maximum current are points of minimum potential and vice versa.

Wave-length.—Consider now the distance between any two consecutive points of minimum current or minimum potential. This distance is a half wave-length. Suppose that the impressed electromotive force is a simple harmonic of frequency 600 p.p.s. Say that we find the wave-length to be 18 miles, the velocity of propagation will be 10,800 miles per second; considerably less than the velocity of propagation of light through a vacuum. To some this numerical illustration may seem as highly improbable, for we are accustomed to hear much of electricity being propagated with the velocity of light. But it should be remembered that this is true under certain particular conditions only. The velocity of propagation of electrical waves of telephonic frequencies over conducting wires may be anything from the velocity of light down to a few inches, or even less than an inch, per second, depending on the inductance, resistance, and capacity of the line. The smaller the velocity the shorter, of course, will be the wave-length for a given frequency. *The wave-length*, as will be seen presently, plays a very important part in this investigation. It is considered here as one of the characteristic constants of wave propagation. I am not aware that previous investigators of the propagation of long electrical waves have devoted any serious attention to this characteristic constant.

Attenuation Constant.—There still remains another constant which with the wave-length completely defines electrical wave propagation. It is called here the *attenuation constant*. To bring out its physical meaning consider two consecutive half wave-lengths at any moment. The one nearest to the transmitting apparatus shall be denoted by A and the other by B. The wave energy stored up in the medium surrounding A is greater than that stored up in the medium surrounding B. Hence wave energy is gradually dissipated during its propagation from the transmitting to the receiving apparatus, and therefore the amplitude of both current and potential become smaller as the energy progresses along the transmission line. Let U be the amplitude of the current at the transmitting end, and U_s be the amplitude at a distance s, then if the line be considered infinitely long

$$\frac{U_s}{U} = e^{-\beta s}$$

where e is the base of Naperian logarithms. The constant β is called here the attenuation constant. The mathematical expression for β is well known

$$\beta = \sqrt{\tfrac{1}{2} p\, C\, [\sqrt{p^2L^2 + R^2} - p\, L]}$$

where L, R, C, are the inductance, resistance, and capacity, respectively, of the wave conductor per unit length, and p is the frequency [illegible]d. Much confusion exists in the minds of physicists [illegible]o the real significance of this constant, and as to the true cause of current attenuation. It is usually stated that the capacity of the line, acting as it does somewhat like a shunt, is the cause of all the trouble experienced in electrical wave transmission. This statement contains a small part of the truth, only, and for that reason may and actually has become misleading. The fact that a conductor possesses inductance and capacity shows that the medium surrounding it is capable of storing up energy, which, indeed, is a blessing; it cannot possibly signify that energy propagated along it will be dissipated; and if capacity cannot cause a loss of energy, how can it possibly cause an attenuation of current? The dissipation is due to imperfect conductivity of the wire, and to that alone. Inductance and capacity regulate it, they do not cause it.

Consider now the manner in which this regulation is effected. The dissipation of the energy transmitted occurs at the time when it is stored up in the medium as magnetic energy; for if the medium surrounding an element ds of the transmission wire contains a quantity $d\,W$ of magnetic energy, then a current x must flow in that element such that

$$d\,W = \tfrac{1}{2}\, L x^2\, d\,s$$

Let dH be the rate of dissipation in that element, then

$$d\,H = Rx^2\,d\,s$$

Suppose now that by some means we increase L to $n^2\,L$, the medium surrounding the elements ds will store up the same amount $d\,W$ of magnetic with one n^{th} of the current, for

$$d\;W = \tfrac{1}{2}\,n^2\,L\,(x/n)^2\,d\,s\,,$$

Let dH_1 be the rate of dissipation in this case then

$$d\,H_1 = R\,(x/n)^2\,d\,s = d\,H/n^2$$

It follows, therefore, that during the transmission of a given quantity of energy over a conducting wire the dissipation will be diminished by increasing the inductance of the wire, for if the wire have high inductance then small currents are required to transmit a given quantity of energy, and small currents incur small ohmic resistance losses.

By increasing the inductance the efficiency of transmission is increased just as effectively as by increasing the conductivity of the transmission wire.

Distortionless Wave Conductors.—Another important advantage is gained by increasing the inductance. The expression for β given above shows that attenuation depends on frequency; it increases with it. Hence, in telephonic transmission where waves of complex harmonic frequencies are propagated over the line there will be distortion of the waves, because upper harmonics will be attenuated more vigorously than the lower frequencies. This results in a distortion of speech, which is noticed in long-distance telephonic transmission as defective articulation. Some instructive experiments bearing upon this point will be described presently. High inductance obviates this difficulty. To illustrate—suppose that the inductance is large in comparison to the resistance, the expression for β will reduce to

$$\beta = R\,/\,2\,\sqrt{C/L}.$$

It is independent of the frequency. All frequencies are attenuated alike, so that high inductance not only diminishes attenuation but also renders the circuit distortionless. Such a circuit is the ideal circuit for telephonic and telegraphic wave transmission.

Mr. Oliver Heaviside, of England, to whose profound researches most of the existing mathematical theory of electrical wave propagation is due, was the originator and most ardent advocate of wave conductors of high inductance. His counsel did not seem to prevail as much as it deserved, certainly not in his own country. I trust that the physical view of attenuation described above in the terms of the dissipation of energy which is transmitted over the wire will help to elucidate Mr. Heaviside's theory of high inductance wave conductors.

Wave Propagation over Non-Uniform Conductors.—But Mr. Heaviside's proposition to employ wave conductors of high inductance contained a serious difficulty which his mathematical theory was not capable of overcoming. The difficulty is this: How can a wave conductor be constructed so as to have a high inductance? Ordinary circuits can be endowed by as much inductance as may be required by simply introducing a coil of proper dimensions, with or without an iron core, into it. But this will never do in the case of a wave conductor; for a coil introduced that way will act by reflection as a barrier to electrical waves. Acting on a suggestion made by Mr. O. Heaviside[1] in 1893, wave propagation experiments over long wave conductors containing a certain number of coils in series at periodically recurring points have actually been tried by telephone engineers; the results obtained have invariably proved most disappointing. I shall return to this point later on in connection with the description of experiments given further below. Suffice it to state here that all attempts to increase the inductance of a wave conductor by the introduction of inductance coils at periodically recurring points failed, because they had no mathematical theory to guide them, so as to avoid the difficulties of wave reflection by inductance coils introduced that way. It is hardly worth while to enter here into a discussion of the many other attempts at increasing the inductance of a wave conductor by devices which had neither theory nor experiment to recommend them. In fact, most of them were absurd on the face of it.

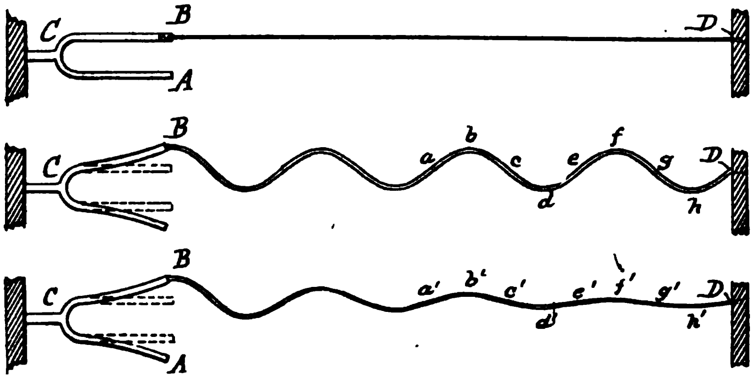
The first mathematical theory dealing with wave propagation over conductors of this kind was presented by the author before this INSTITUTE on March 22d, 1899.[2] A more complete theory is given in the second part of this paper. The main features of

---

[1] Heaviside, O.—"Electromagnetic Theory," vol. i., p. 485.

[2] Pupin, M. I.—"Propagation of Long Electrical Waves;" TRANSACTIONS, vol. xvi., p. 93, 1899.

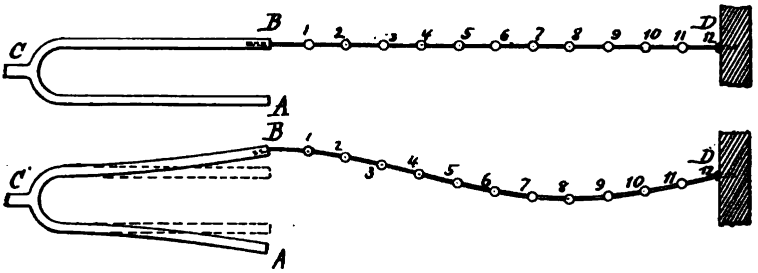
this theory are extremely simple and can be explained by a simple mechanical illustration. Consider the arrangement of Fig. 1. A tuning fork has its handle *C* rigidly fixed. To one of its prongs is attached a flexible inextensible cord *B D*. One terminal of the cord is fixed at *D*. Let the fork vibrate steadily, the vibration being maintained electromagnetically or otherwise. The motion of the cord will be a wave motion. If the frictional resistances opposing the motion of the cord are negligibly small the wave motion will be approximately that of stationary waves as in Fig. 2. The direct waves coming from the tuning fork and the reflected waves coming from the fixed point *D* will have nearly equal amplitudes and by their interference form approximately stationary waves. If, however, the frictional resistances are not negligibly small, then there will be dissipation of the propagated wave energy. Hence the direct and the reflected waves will not have equal amplitudes, and, therefore, their interference will not result in stationary waves. The attenuation of the wave is represented graphically in Fig. 3. Experiments will show that, other things being equal, increased density of the string will diminish attenuation, because a larger mass requires a smaller velocity in order to store up a given quantity of kinetic energy, and smaller velocity brings with it a smaller frictional loss. This is a striking mechanical illustration of a wave conductor of high inductance. It should be observed here that an increase of the density will shorten the wave-length.



FIGS. 1, 2, 3.

Suppose now that we attach a weight, say a ball of beeswax, at the middle point of the string, in order to increase the vibrating mass. This weight will become a source of reflections and less wave energy will reach the point D than before. The efficiency of transmission will be smaller now than before the weight was attached. Subdivide now the beeswax into three equal parts and place them at three equidistant points along the cord. The efficiency of wave transmission will be better now than it was when all the wax was concentrated at a single point. By subdividing still further the efficiency will be still more improved; but a point is soon reached when further subdivision produces an inappreciable improvement only. This point is reached when the cord thus loaded vibrates very nearly like a uniform cord of the same mass, tension, and frictional resistance. Such a loaded cord with a tuning fork attachment is represented in Fig. 4.

If an increase in efficiency of wave transmission over a cord thus loaded is to be obtained, it is evident that the load must be properly subdivided and the fractional parts of the total load must be placed at proper distances apart along the cord, otherwise the detrimental effects due to reflections resulting from the discontinuities thus introduced will more than neutralize the beneficial effects derived from the increased mass.



Figs. 4 and 5.

The problem of finding the proper distance at which the loads should be placed is a definite mathematical problem of Analytical Mechanics, but unfortunately it was never solved. Fig. 5 represents a cord carrying loads at proper distances apart. Experiments with cords of this kind will soon convince one that the distance between the loads should be considerably smaller than one-half of the wave-length of the wave which is to be transmitted. So that though a given cord may be properly loaded for some wave-length it will not be properly loaded for shorter wave-lengths. It is impossible to load a cord in such a way as to make it equivalent to a uniform cord for all wave-lengths; but if the distribution of the loads satisfies the requirements of a given wave-length it will also satisfy them for all longer wave-lengths. It should be observed now that the wave-length which is considered here is not the wave-length of the cord without the loads, but the wave-length which the frequency under consideration will have on the properly loaded cord, or what is the same thing, on a uniform cord of the same mass, tension, and frictional resistance, as the loaded cord. This point is of fundamental importance, for the wave-length corresponding to a given frequency may and generally will be much shorter on the loaded cord than on the cord without the loads.

A cord of this kind is a mechanical analogy to an electrical wave conductor. The mathematical law in accordance with which such a cord moves is the same as that in accordance with which the electrical current is distributed over the wave conductor under the action of similar forces. The reason for that is not far to seek. We have the same reactions in both cases, viz.:—Kinetic or mass reaction, tensional reaction, and resistance reaction in the case of the cord. Electro-kinetic reaction, capacity reaction, and ohmic resistance reaction in the case of the wave conductor. The mathematical form of these reactions is the same in both cases, hence one is an exact analogy of the other.

The insertion of inductance coils at periodically recurring points along the wave conductor, represented in Fig. 3 of Part II., produces the same effect upon electrical wave transmission as the distribution of the small loads along the stretched cord of Fig. 4 produces upon mechanical wave transmission along the cord. The mathematical theory of wave propagation over non-uniform conductors of this kind is given in Sections I and II of the Second Part of this paper. This theory is, of course, at the same time the mathematical theory of wave propagation over a loaded cord described above. The main object of this theory is find an answer to the question: *Under what conditions are non-uniform conductors described in these two sections equivalent to their corresponding uniform conductors?* The answer which the mathematical theory gives to the question just proposed is definite. To formulate it introduce here a convenient technical term. Consider the distance between two consecutive inductance points, that is, the points at which the inductance coils are introduced. Denote it by l, and let the wave length which is to be transmitted be λ. Now introduce an angle φ such that

$$\varphi / 2\pi = l / \lambda.$$

The angle φ shall be called the *angular distance* between the inductance points, or inductance sources. The angular distance 2π corresponds to the wave-length. The law which determines the degree of equivalence between a non-uniform conductor and its corresponding uniform conductor can now be stated as follows: **A non-uniform conductor is as nearly equivalent to its corresponding uniform conductor as sin $\varphi/2$ is to $\varphi/2$.**

It is evident that φ is inversely proportional to the wave-length, so that for a given distance between the reactance points the degree of equivalence diminishes as the wave-length diminishes. If a wave of complex harmonic frequency, such as occur in telephony, be transmitted over a non-uniform conductor, then the action of the conductor will be different for the different components of this complex harmonic wave. If, however, the non-uniform conductor acts with sufficient approximation as a uniform conductor toward the highest important frequency of this complex wave then its approximation to a uniform conductor will be even higher for the lower frequencies and thus for all the frequencies of the wave. A numerical example will illustrate this point more clearly. It is well, however, to state more fully the meaning of the expression "equivalence between a non-uniform conductor and its corresponding uniform conductor." All that we can predicate of a wave of a given frequency is that it has a certain wave-length and a certain attenuation constant. Hence, if a wave of a given frequency has the same wave-length and the same attenuation constant on a non-uniform conductor as it has on the corresponding uniform conductor then the two conductors are equivalent to each other. If these two quantities differ by, say, three per cent., then an approximate equivalence up to within three per cent. exists.

Consider now the following numerical example: A twin conductor, such as employed for telephone cables, has a length of 250 miles. Let its constants have the following values per mile:

Inductance = 0.
Resistance = 9 ohms.
Mutual capacity = .074 Microfarads.

According to the high but definite standard which the New

York Telephone Company employs the limiting-distance of telephony over such a cable is 39 miles. According to the lower standard which is maintained in long-distance telephone work the limit would be 78 miles. The results obtained by me experimentally seem to verify these figures. I find that at a distance of one hundred miles telephony over such a cable is very poor, in fact, impracticable, and at a distance of 125 miles impossible. It is proposed now to decrease attenuation and distortion over such a cable by the insertion of inductance coils at periodically recurring points. The attenuation constant β in this case is given by the formula[1]

$$\beta = \frac{R}{\sqrt{2}}\sqrt{\frac{C}{L}}.$$

Say that it is required to have $\beta = .015$. Assume that the introduction of the inductance coils adds 9 ohms per mile, so that $R =$ 18 ohms. These values of R and C require $L = .056$ henrys. The attenuation factor at a distance of 250 miles would be

$e^{-250\beta} = \frac{1}{40}$, (roughly). That is, 2½ % of the current leaving

the transmitting end will reach the receiving end. This is quite sufficient for telephonic purposes; but it should be observed that better efficiency of transmission could be obtained by making L larger. Notice now that the attenuation factor for this cable without the coils would be, for a frequency of 600 p.p.s., roughly, $\frac{1}{25 \times 10^4}$ that is, with a given initial current, the current at the receiving end would be 6000 times larger with the coils than without them.

The next step is to find the wave-length for the highest important frequency in telephony over a *uniform wave conductor* having $L = .056$ henrys, $R = 18$ ohms, $C = .074$ microfarads. The best telephone practice assumes that 750 P. P. S. is the highest frequency of any importance. The wave-length corresponding to this frequency over a *uniform conductor* of this description is obtained from the formula[1]

$$\lambda = \frac{2\pi}{p\sqrt{2LC}} = 14.6 \text{ miles},$$

approximately.

---

[1] See Equation (4*a*), Sect. I., Part II.

Suppose now that at each mile we place a coil of inductance $L = .056$ henry and a resistance $R = 9$ ohms. The angular distance φ for frequency 750 P. P. S. of the non-uniform conductor thus obtained will be $2\pi / 14.6$ The degree of equivalence of this non-uniform conductor to its corresponding uniform conductor is measured by the degree of equivalence of $\sin \pi/14.6$ and $\pi / 14.6$. Now $\sin \pi / 14.6$ differs from $\pi/ 14.6$ by less than one per cent. of the value of $\pi/14.6$; hence for a frequency of 750 P. P. S. the wave-length and the attenuation constant on the non-uniform conductor will differ from the wave-length and attenuation constant on the corresponding uniform conductor by less than one per cent. of the values of these constants. Such a difference cannot be detected by any of the experimental methods which are at present available for investigating wave propagation. In telephonic transmission the ear could not detect it. For lower frequencies the differences will be even considerably smaller. Hence, the non-uniform conductor thus obtained will represent a uniform, non-attenuating, distortionless conductor for telephonic transmission.

It should be observed here that in the case of a submarine cable of say 2,000 miles the attenuation constant should be much smaller than the value of β given above, in order to have a sufficiently small attenuation factor. Now the capacity per mile of a submarine cable is about four times as large as the capacity of the telephone cable just described. Hence, both on account of the long distance and also on account of the much increased capacity, the inductance per mile will have to be much larger than in the case just discussed. But high inductance and large capacity will give a very short wave-length. For instance, if in the case of the submarine cable having six times the capacity we employ an inductance six times as large as in the case of the telephone cable we shall obtain for the frequency of 750 P.P.S. a wave-length of only $14.6 \div 6 = 2.43$ miles. Hence, since the inductance coils will have to be placed apart at one-sixth of the distance employed in the case of the telephone cable, the distance between them will be about 880 feet. The distance between the inductance coils depends entirely on the circumstances of each particular case. But in all cases the rule given above contains the necessary and sufficient directions.

This rule and the method based upon it are recommended by the mathematical theory developed in Part II of this paper for the construction of distortionless wave conductors of high efficiency of transmission. It will be shown now in how far this theory is confirmed by experiment.

EXPERIMENTAL PART.

a. Description of the Experimental Cable.—A so-called artificial cable possessing the above constants was constructed by me for the purpose of testing experimentally the mathematical theory developed in Section III of Part II. Previous experiments in this line will be found in the author's paper of March 22d, 1899, cited above.

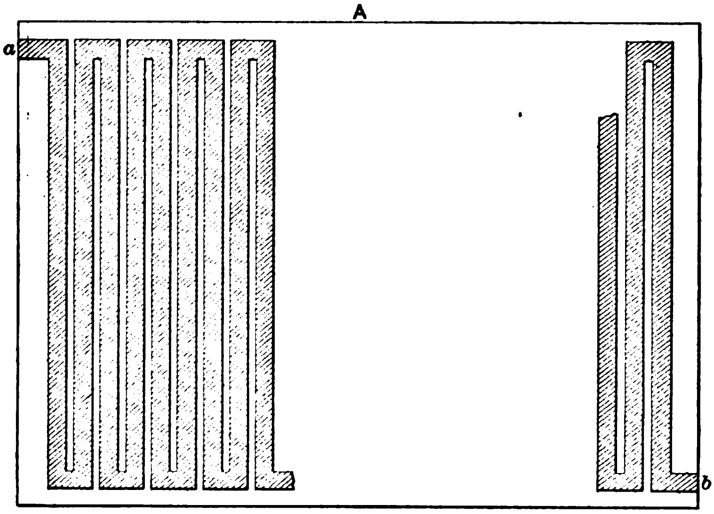


FIG. 6.

The cable has 250 sections. One of these sections is represented in Fig. 6. It consists of a sheet *A* of paraffined paper. On each side of this sheet is a strip of tinfoil *a b*. The resistance of this strip is approximately 9 ohms. The capacity of the condenser formed by the two strips is .074 microfarads approximately. 250 sections of this kind connected in series represent a cable of 250 miles in length having a resistance of 9 ohms and a capacity of .074 microfarads per mile. That such is actually the case was verified experimentally, as will be shown presently. In Fig. 8 the straight lines A B C D A_1 B_1 C_1 D_1 represnt these sections. The upper lines represent one side of the cable, and the lower lines represent the other side. The sections can be connected in series by couplers to which these sections are attached. One of these couplers is represented in Fig. 9. A wooden strip *A B* has holes drilled through it at regular intervals. Through each hole passes a bolt *c*, the diameter of which is smaller than the diameter of the hole. Two hard rubber washers *a* and *b* hold the bolt in place and prevent it from touching the wood. A nut holds the brass plates *d* in place. Two consecutive brass plates *dd* can be conductively connected by the plug *e*. Screws, as indicated, connect the terminals *ff* of the condenser sections and of the coils *gg* to the brass plates. These brass plates are indicated in Fig. 8 by numerals 1, 2, 3,.... When the plugs are out, then the consecutive sections of the cable are connected to each other by the inserted coils (see Fig. 8). The plugs being in the coils are short-circuited, and the consecutive sections of the cable are connected to each other directly by the plugs. In this case we have a uniform cable; in the former case we have a non-uniform cable of 250 miles length, with inductance coils inserted at each mile. The coils are wound as represented in Fig. 7. The twin coils aa_1, bb_1, cc_1 of Fig. 8 are represented in Fig. 7 by coils *aa* and *bb*.

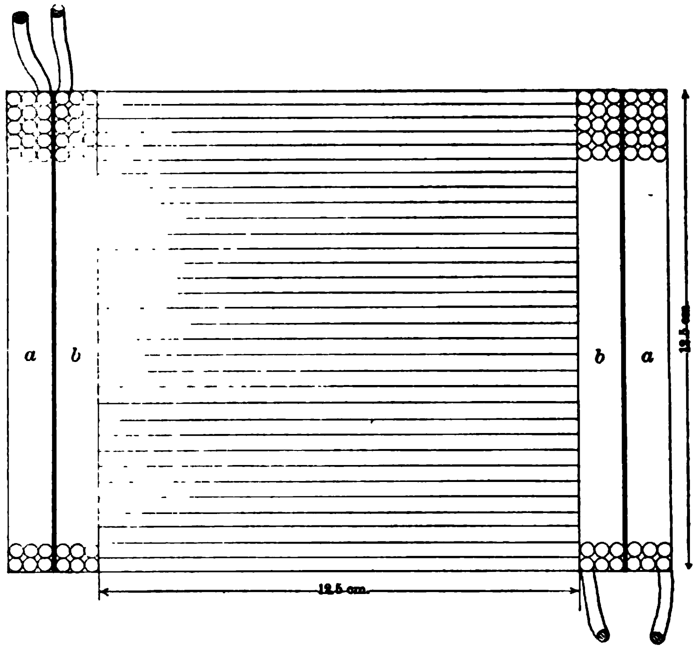


FIG. 7.

These two coils are wound on one spool, and are separated by a sheet of cardboard indicated by a black line in Fig. 7 which is 1-64th of an inch thick. The coil when finished is boiled in beeswax at a temperature of about 280° Fahrenheit, in order to drive all the moisture out and insure good insulation. The dimensions of the coil are given in Fig. 7. Each coil had 580 turns of No. 20 wire B. & S. The average inductance of one of these coils is .030 henry, and the mutual inductance .028 henry. Each coil, therefore, when connected into the line, as indicated in Fig. 8, has an effective inductance of

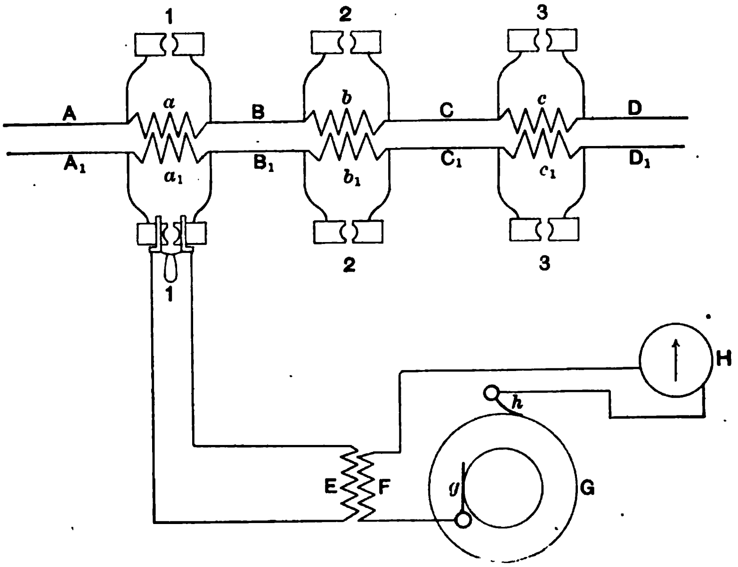


FIG. 8.

.058 henry. This method of bringing the corresponding coils of the two sides of the cable into close relation by mutual induction is not necessary; it is a matter of convenience and economy.

The cable sections are divided in five groups of 50 each, and each of these groups is enclosed in a separate box. Each box represents, therefore, 50 miles of the cable. Fig. 10a is a reproduction from the photograph of one of these boxes. The box marked A is the cable box. On two opposite sides are five rows B.... of binding posts, each row having 10 pairs. They are the terminals of the condenser sections. From these binding posts double cotton covered wires which have been boiled in beeswax lead to the row of brass plate couplers (Fig. 9) indicated in the picture by letters *a*, *b*, *c*,.... These boxes were made for me by the well-known mechanician, Mr. E. V. Baillard, to whom my sincere thanks are due for the keen interest which he took in this exceedingly laborious work. The rest of the work on the cable was done in the Columbia University laboratory for electro-mechanics. The insulation per section was about 50 megohms.

b.—Theory of the Experimental Method.—The mathematical theory of Section III, Part II, states that up to a frequency of 750 p.p.s. the waves will have to within an approximation of one per cent. the same wave-length and the same attenuation constant on the cable just described as on its corresponding uniform conductor. This is the side from which experiment has to approach the theory. The method employed in this investigation has, therefore, for its object the determination of wave-length and attenuation constant. Its theory can be stated as follows:

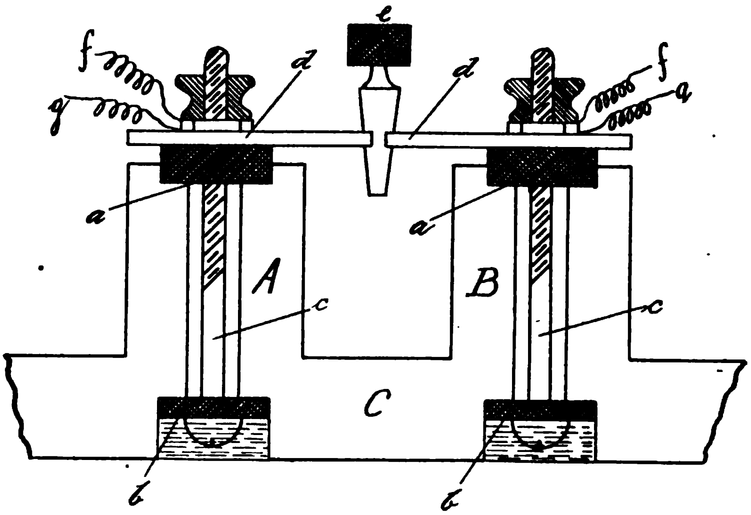


Fig. 9.

The current η at any point ξ of a uniform loop can be expressed.[1]

---

[1] M. I. Pupin:—Propagation of Long Electrical Waves, equ. (7); **Transactions**. vol. xvi., p. 93, 1899.

$$\eta = A \left\{ e^{\beta\xi} \sin (pt - a\,\xi) + e^{-\beta\xi} \sin (pt + a\xi) \right\}$$

Let $M(\eta)$ denote the mean value of the current between $t = t_1$ and $t = t_1 + T/2$, then

$$M(\eta) = \frac{y_0}{2} \left(e^{\beta\xi} + e^{-\beta\xi} \right) \cos (pt_1 - a\,\xi)$$

Here ξ is the distance from the middle point of the loop. The time is counted from the moment when η is zero at the middle point. If we then determine the mean values from the moment when η vanishes at the middle point we shall have $t_1 = 0$ and

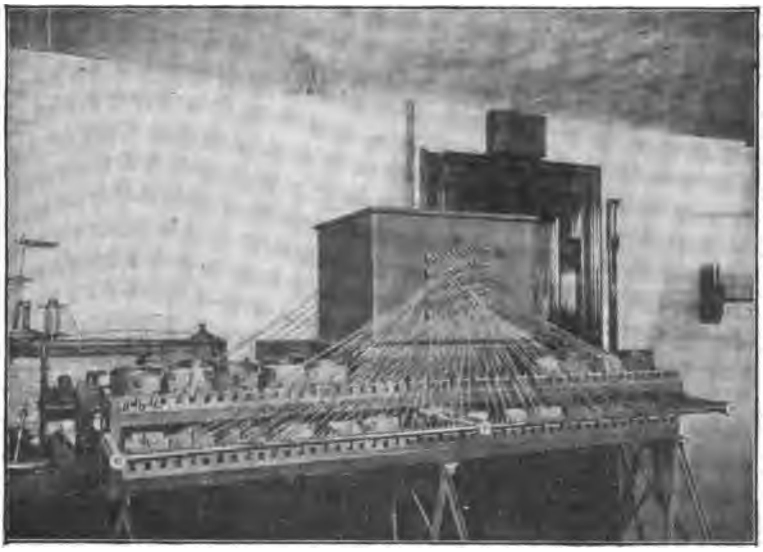


FIG. 10 A.

$$M(\eta) = \frac{y_0}{2} \left(e^{\beta\xi} + e^{-\beta\xi} \right) \cos a\,\xi$$

or since $\lambda = 2\pi/a$, where λ is the wave-length

$$M(\eta) = \frac{y_0}{2} \left(e^{\beta\xi} + e^{-\beta\xi} \right) \cos \frac{2\pi}{\lambda}\,\xi \qquad (1)$$

y_0 is evidently the mean value of the current at the middle point. This formula forms the basis of the experimental method employed here. From it the wave-length and the attenuation constant were determined.

c. Determination of the Wave-length.—1. To investigate the wave-length and the attenuation constant of a given frequency it was necessary to impress a simple harmonic electromotive force upon the cable. This was obtained as follows:— A small alternator of thirty poles running at a normal speed of 2400 revolutions per minute was employed. It gives a complex harmonic E. M. F. in which the third and fifth harmonic are quite strong. At the normal speed the frequency of the fundamental was 600 p.p.s. By transformation as indicated in Fig. 10 the upper harmonics were weeded out by tuning, In this diagram A is the alternator. The secondary circuit D, E, F, G, contains a condenser F, and an auxiliary coil E. By adjusting the capacity of condenser F and the inductance of coil E, the impedance of this secondary circuit for the fundamental frequency can be reduced to a minimum, in which case the fundamental current in this circuit is by far predominant. Under these conditions the E. M. F. impressed upon the tertiary coil H, which connects to the line, is very nearly simple harmonic. This was verified by plotting experimentally the E. M. F. curve in the tertiary circuit. The point of resonance was detected by connecting the terminals of condenser F to a multicellular voltmeter K and watching for the maximum rise of the potential. While the observations which will be described presently were made the reading of this voltmeter was continually watched. A change in it indicated a change in speed

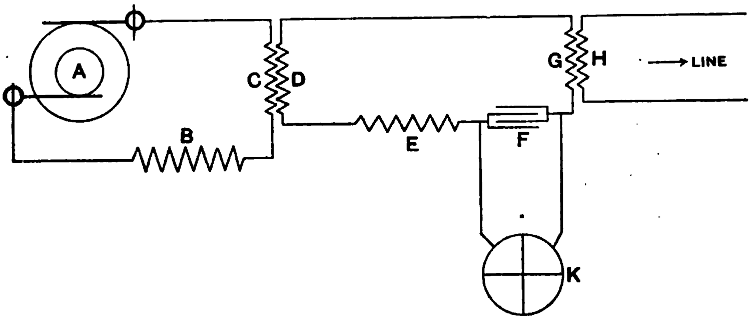


FIG. 10.

and impressed E. M. F. and the observations had to be suspended until the voltmeter returned to the same reading. Considering the variability of the electrical pressure in a University plant where every one of the many departments draws its current from the same source, it will be readily seen that these observations were somewhat trying.

2. To determine the mean value of the current a Townsend contact-maker (G, Fig. 8) was used.[1] Its circumference was divided into thirty equal parts, since the alternator had thirty poles. Every other section of the circumference was connected to a ring g. This ring and the circumference were connected to the rest of the circuit, $g\,F\,H\,h$, by two brushes $g\,h$. The contact-maker was mounted on the shaft of the alternator. The time interval, of half a period, during which the contact lasted, could be shifted by shifting the brush h along the circumference of the contact-disk. H is a Rowland-D'Arsonval galvanometer suitably shunted so as to keep the readings within a desirable range. The current readings were obtained as follows: A two-pole contact spring-jack (1, Fig. 8) was inserted across the terminals of an inductance coil, say, a_1, as indicated. The coil was thus shunted by circuit 1 E. This circuit contained a small coil e and one or two ordinary 16-c.-p. incandescent lamps in series with it. The coil acted inductively upon the circuit containing the contact-maker and the galvanometer. A simple consideration will show that the galvanometer reading was proportional to the mean value of the current flowing through the inductance coil a_1 during the half-period corresponding to the position of the brush h. Suppose now that this brush is set in such a way as to give the maximum reading when the contact-spring-jack is across the inductance coil at the middle point of the cable. Then, as shown in equation (1), the reading at any other inductance coil will be proportional to

$$\left(e^{\beta\xi} + e^{-\beta\xi}\right) \cos \frac{2\pi}{\lambda}\xi$$

where ξ denotes the distance of the inductance coil under consideration from the middle point. This expression passes through zero whenever ξ is an odd multiple of the quarter wave-length, and the reading passes then from one side of the zero position to the other. The brush h was, therefore, set so as to give the maxi-

---

[1] See TRANSACTIONS, vol. xvii., No. 1, Jan., 1900.

mum reading at the middle point of the line. Then the spring-jack was run along the line and the sign of the readings noted at 1, 2, 3.,....etc. The number of reversals of readings corresponding to a given length of the line was counted.

The reversals occur whenever ξ is an odd multiple of $\lambda/4$. Suppose that five reversals occurred in the distance of 41 miles. It means that 9/4 wave-lengths cover the distance of 41 miles; hence the wave-length is

$$\lambda = 18.2 \text{ miles.}$$

This was found to be the case with a frequency of 600 P. P. S. The wave-length calculated from the formula

$$\lambda = \frac{2\pi}{p\sqrt{2LC}}\,.$$

$$p = 2\pi \times 600.$$
$$L = .058.$$
$$C = .074 \times 10^{-6}$$

gives $\lambda = 18.1$ miles.

The agreement between the calculated and the observed wave-length was extremely good for this frequency, considering the inequality of the cable sections which necessitates taking for L and C average values. Following is a table of wave-lengths for other frequencies, giving both the observed and the calculated values.

TABLE OF WAVE LENGTHS.

FREQUENCY.	$\lambda_{\text{obs.}}$	$\lambda_{\text{calc.}}$
625	17	17.3
600	18.2	18.1
450	24	24.1
260	41.4	41.7
245	44	44.4
230	48	48.2

At the frequency of 600 P.P.S. the non-uniform cable has 18 coils per wave-length. At the lower frequencies the number of coils per wave-length is larger, and therefore the cable approximates then its corresponding uniform conductor even more closely than at the frequency of 600 P.P.S. But the approximation at this higher frequency is already so close that no difference in the behavior of the cable at the various frequencies experimented with and given above could be detected experimentally. As far as the wave-length determination is concerned the agreement between theory and experiment is very satisfactory.

3. To determine the wave-length on the cable without the coils plugs (see *e*, Fig. 9) were put in 1, 2, 3.... The readings were taken as follows: The two-pole spring-jack was inserted across a pair of plates, say 1. Then the short-circuiting plug (see *e*, Fig. 9) was taken out and the deflection in the galvanometer noted. The number of reversals was counted as before, and from these the wave-length was estimated. The value of the wave-length thus determined for a frequency of 600 P.P.S. was 126. Its calculated value was 125. Thus the insertion of the coils reduces the speed of propagation to one-seventh of its original value since it shortens the wave-length to that extent.

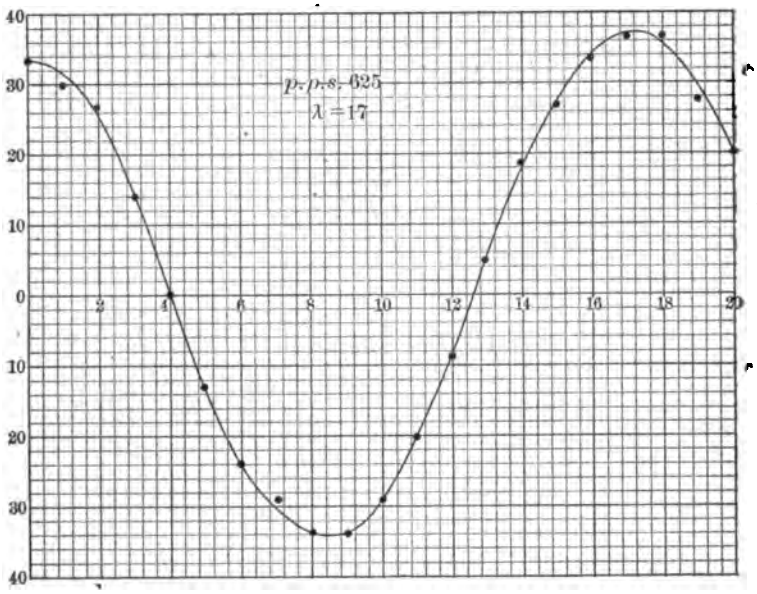


FIG. 11.

d. Determination of the Attenuation Constant — First

Method.—It was shown above that the equation of the curve of the mean value of current is

$$y = \frac{y_0}{2}\left(e^{\beta\xi} + e^{-\beta\xi}\right)\cos\frac{2\pi}{\lambda}\xi$$

where y is the mean value of the current at the distance ξ from the middle point of the cable and y_0 is the mean value at the middle point when the brush h of the contact-maker is set to give a maximum deflection at this point. In Fig. 11 and Fig. 12 two such curves are given. In these curves the abscissæ represent the number of the coil at which the reading was taken, and the ordinate represents the galvanometer reading at the corresponding coil.

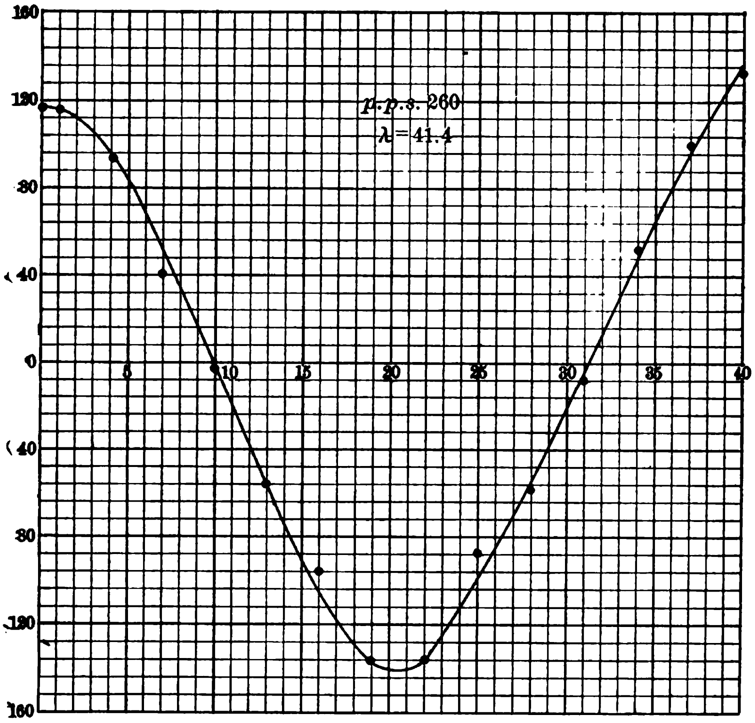


FIG. 12.

An attempt was first made to determine β from these curves.

Let $y_{\frac{\lambda}{2}}$ be the value of y at $\xi = \frac{\lambda}{2}$, then

$$y_{\frac{\lambda}{2}} = -\frac{y_0}{2}\left(e^{-\frac{\beta\lambda}{2}} + e^{-\frac{\beta\lambda}{2}}\right)$$

Since $\frac{\beta\lambda}{2}$ is small we can also write

$$y_{\frac{\lambda}{2}} = -\frac{y_0}{2}\left(2 + \frac{1}{4}\beta^2\lambda^2\right)$$

Therefore considering the numerical values, only, of y_0 and $y_{\frac{\lambda}{2}}$ we shall have

$$\beta = \frac{2}{\lambda}\sqrt{\frac{2\left(y_{\frac{\lambda}{2}} - y_0\right)}{y_0}}$$

Referring now to curve Fig. 11

$$\lambda \doteq 17$$
$$y_0 = 33.5$$
$$y_{\frac{\lambda}{2}} = 34$$

$$\frac{2}{\lambda}\sqrt{\frac{2\left(y_{\frac{\lambda}{2}} - y_0\right)}{y_0}} = \frac{2}{17}\sqrt{\frac{1}{33.5}} = .02 = \beta$$

The value of β calculated from the formula

$$\beta = \frac{R}{\sqrt{2}\,10^3}\sqrt{\frac{C}{L}}$$

gives $\beta = .0141$

if we assume for L, C, and R the following average values: $L = .058$, $C = .074 \times 10^{-6}$, $R = 17.5$.

The question now arises: What degree of accuracy can be claimed for this experimental determination of β? The expression for β contains the difference of quantities which are nearly equal. Now this difference is very near the limit of the errors of observation, the limit being quite considerable on account of several reasons. The chief reason is this. The condenser sections of the cable are far from uniform. This lack of uniformity is due, first to the varying thickness of the tinfoil which makes the resistance vary from section to section. Secondly, the sections are heated before compression is applied to them. This heating is of course not quite uniform; the amount of paraffin driven out by the applied pressure is, therefore, different in different sections. Hence the variation of capacity. The result is that the speed of propagation is different in different sections. The difference may amount to as much as 20 per cent. Hence the wave-length will change considerably from point to point of the cable. This will be observed in the curves of Fig. 11 and Fig. 12. Thus in Fig. 11 the first quarter wave-length is four miles long, the second quarter wave-length is 4.5 miles and the average is 4.25. The same variation will be observed in curve of Fig. 12. It is evident, therefore, that the method described above for taking readings at the various points of the cable will not give readings which will follow very strictly the mathematical law of the formula on page 22. Taking all these things into consideration, it is evident that this method just pointed out for determining experimentally the attenuation constant, is not strictly applicable to our cable.

Another method will be described now which determines the attenuation constant not from the one-half wave-lengths, only, near the middle of the line, but takes all the waves corresponding to a long length of the line into consideration. The wave-length determination given above agreed so much better with the theory for the very reason that the method employed gave the average wave-length and not the wave-length at any particular point of the cable.

Although the curves of Figs. 11, 12 and 13 do not enable us to calculate β accurately they are still of considerable importance. *First*, they show that the cable, though it has a large resistance, possesses, nevertheless, a small attenuation constant. This is particularly well shown in the curve of Fig. 13. This curve represents the mean square of current curve at the the various coils. The readings were obtained in this case by dispensing with the sliding contact arrangement and putting in place of E an electrodynamometer. This mean square curve represents a very near approach to the stationary wave form, which shows that the attenuation is extremely small. *Secondly*, the smoothness of the curves 11, 12, and 13 shows that the non-uniform cable acts, even at the frequency of 625 P. P. S., just like a uniform cable. This, in fact, was the principal aim of this experimental research.

Second Method of Determining β.—The value of β was determined from

$$y = \frac{y_0}{2}\left(e^{\beta\xi} + e^{-\beta\xi}\right)\cos\frac{2\pi}{\lambda}\xi$$

as follows: Suppose that at a considerable distance from the point $\xi = 0$ we find a point the distance of which is some multiple of $\lambda/2$. Then

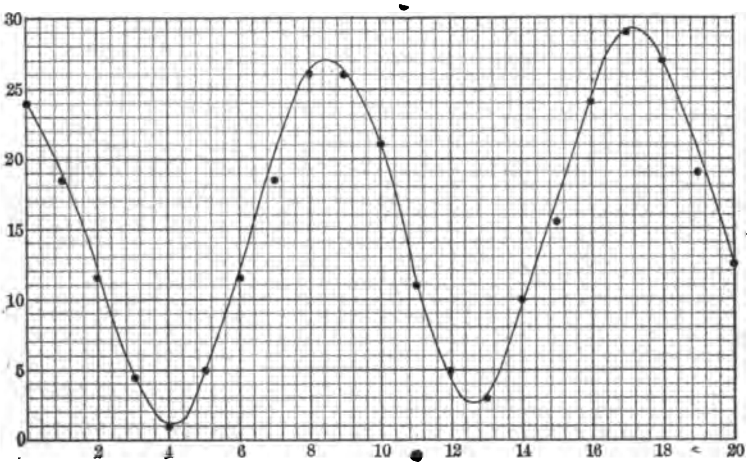


FIG. 13.

$$y_1 = \frac{y_0}{2}\left(e^{\beta\xi_1} + e^{-\beta\xi_1}\right)$$

This was done experimentally by shifting the brush h (Fig. 8) until the maximum reading was obtained at the middle point of the line. It was 152 scale divisions—that is, $y_0 = 152$. Then the spring-jack was carried to the beginning of the cable and passed along from coil to coil until the galvanometer reading passed through a maximum. The distance ξ_1 of this point from $\xi = 0$ was 145. The reading actually obtained was 60, but this reading was obtained from a shunt wire, and the reading as calculated from the shunt was 630. Now, when ξ_1 is so large that the omission of $e^{-\beta\xi_1}$ in comparison to $e^{+\beta\xi_1}$ involves an error of the same order of magntude as the errors of observation, we have the simplified formula

$$y_1 = \frac{y_0}{2} e^{\beta\xi_1}$$

Therefore,

$$\beta = \frac{1}{\xi_1} \log \frac{2\,y_1}{y_0}$$

In the case before us

$$\beta = \frac{1}{145} \log \frac{1260}{152} = .0145$$

The calculated value of β as given above is .0141. Experiment and theory agree quite satisfactorily. *The equivalence between the non-uniform cable and its corresponding uniform conductor up to 625 p.p.s. has therefore been established experimentally.*

INTERNAL REFLECTION OF ELECTRICAL WAVES IN A NON-UNIFORM CABLE.

It remains to be shown now that when the distribution of the inductance coils over the cable does not render the cable approximately equivalent to its corresponding uniform conductor, then there will be serious internal reflections which will diminish the efficiency of wave transmission.

For this purpose the inductance coils were connected in groups of ten; one of these groups was inserted into the cable every ten miles, so that the total inductance of the cable was now the same as before. A simple harmonic E. M. F. of 260 p. p. s. was impressed upon the cable. The wave-length of a wave of this frequency on the corresponding uniform conductor was found (see Fig. 12) to be 41.4 miles so that the inserted inductance coils were apart at a distance which is equal to about one-quarter of the wave-length on the corresponding uniform conductor. The degree of equivalence between this non-uniform cable and its corresponding uniform conductor is the same as the degree of equivalence between sin $\pi/4$ and $\pi/4$; that is to say, the resemblance between the two is very small.

Theory of the Experiments on Internal Wave Reflections.—The current at any point between two consecutive groups of coils can be written as follows:

$$y = A\,e^{\beta\xi} \sin (pt - a\,\xi) + B\,e^{-\beta\xi} \sin (pt + a\,\xi)$$

that is, there are two waves, one a direct one, and the other a reflected one. This equation can also be written:

$$y = \sqrt{A^2\,e^{2\beta\xi} + B^2\,e^{-2\beta\xi} + 2\,A\,B\,\cos 2\,a\,\xi}\ \sin (pt - \epsilon)$$

where

$$\tan \epsilon = \frac{A\,e^{\beta\xi} - B\,e^{-\beta\xi}}{A\,e^{\beta\xi} + B\,e^{-\beta\xi}} \tan a\,\xi$$

Let $M\,(y)$ stand for the mean value of the current, then

$$M\,(y) = \frac{1}{\pi}\sqrt{A^2\,e^{2\beta\xi} + B^2\,e^{-2\beta\xi} + 2\,AB\cos 2a\xi}\,\cos (pt_1 - \epsilon)$$

This is a maximum when t_1 is given such a value that $pt_1 - \epsilon = o$. In that case $M\,(y)$ is proportional to the square root of the mean square of the current.

Experiment.—The curve of $M\,(y)$ was obtained in the same manner as the curves of Figures 11 and 12, except in this case the movable brush *h*, Fig 8, was shifted until the galvanometer showed the maximum deflection at every reading. These readings were plotted as ordinates of curve Fig. 14. Points *a b c d* on the axis of abscissæ mark the positions of the groups of inductance coils. The effect of reflections is shown in a very marked manner by the sharp corners and strong depressions. The sharp corners coincide, of course, with the positions of the coils. The rapid rise of the minima points show strong attenuation. To compare the attenuation in this case with the attenuation which exists where the coils are distributed one per mile it is only necessary to obtain from curve 14 the curve of mean square of current and compare it to curve of Fig. 13. Draw then a straight line through two consecutive minima and compare the slope of this line in curve 13 to that of curve 14. It will be found that the slope in this latter case is very much more rapid, and, therefore, the attenuation is very much more powerful; and it should be remembered that in curve of Fig. 14 we have the attenuation which is accompanying a frequency of 260 p.p.s. With a frequency of 625 p.p.s. (the frequency of Fig. 13) the attenuation would be even much more powerful. I intend to continue this particular part of the research in the very near future.

Telephony Over the Non-Uniform Cable.—These experimental results leave no doubt as to the correctness of the prediction which the mathematical theory of Part II makes with regard to telephony over non-uniform cables. Actual experimental tests with transmitters and receivers which were kindly put at my disposal by the New York Telephone Company, for which I feel very grateful to them, verified these predictions completely. Telephonic communication over the whole of the cable was carried on with perfect ease. Both the volume and the articulation of the transmitted sound were all that could be desired. If, however, the inductance coils were cut out and the cable used as a uniform cable, then the transmission was good up to 50 miles, fair up to 75 miles, impracticable at 100 miles, impossible at distances over 112 miles. Increased distance interferes with the transmission over the uniform cable, not only on account of the diminished volume of the sound transmitted, but also on account of the rapid loss of articulation. This manifests itself at first as an apparent lowering of the pitch of the voice just as the theory demands it. My assistant's voice is of an ordinary pitch, if anything a little above the pitch of the average man's voice. When it was transmitted over 75 miles of the uniform cable (that is, the coils being disconnected from it) it sounded like a strong baritone. Over a distance of 100 miles it became so drummy, (this is an expression borrowed from telephone engineers) that it was difficult to understand it, unless nothing but ordinary conversation was carried on and then very slowly, and the speaker had to put his mouth as close to the transmitter as possible and speak out as if he were addressing a big audience. At distances over 112 miles nothing but the lowest notes of the voice could be heard; the articulation was entirely gone. When the coils were all in, then no drumminess in the voice was noticed, and the conversation could be carried on as rapidly as one chose to do. I understand that in long distance work three galvanic cells of the same type of which I had two only were formerly employed by the

American Telegraph and Telephone Company when they employed the old system of transmission.

Effect of internal reflections upon telephonic transmission.—The effect of internal reflection is illustrated even more strikingly by telephonic transmission than it is by the exploration of the simple harmonic wave as represented in Fig. 14. The same distribution of coils was used for telephonic transmission as described above in connection with the internal reflection experiments. A distance of a hundred miles of the cable was employed.

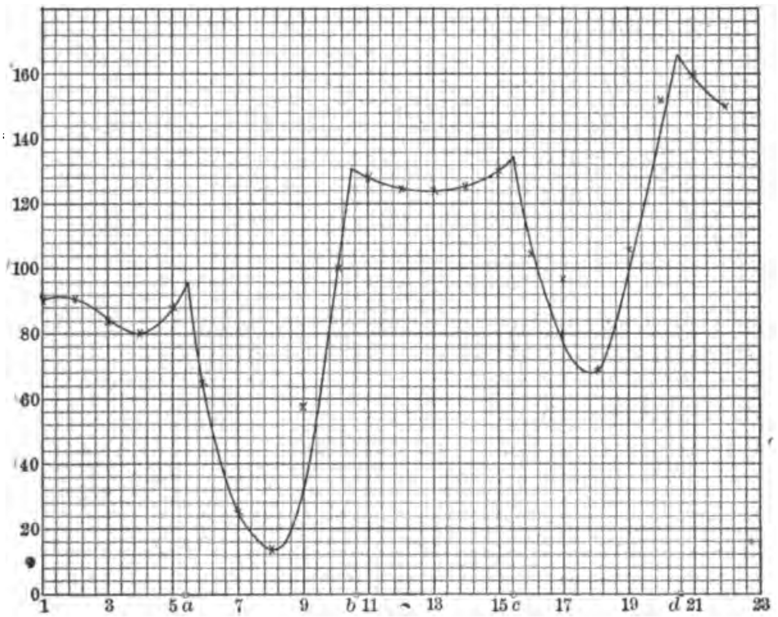


FIG. 14.

Telephonic transmission over this distance was absolutely impossible, although the lowest note in the voice was transmitted quite vigorously, and sounded like the muffled beating of a big drum. Another distribution of the coils was now tried. The coils were divided into groups of five, and these groups were put into the cable at points five miles apart. Transmission over a distance of a hundred miles became intelligible, though with much difficulty; but it was not as good as over the cable without the coils. The drumminess was even more excessive in the former case than in the latter. One had to put his mouth very close to the transmitter, speak very slowly, very loud, and about very ordinary things, otherwise the meaning of the transmitted intelligence would not be caught at all. But if the same distance of cable was employed with the inductance coils placed one mile apart as the mathematical theory suggests then the voice of the sender sounded just as if he stood right before the receiving operator. It was not necessary to stand near the transmitter at all, in order to be heard at the other end. There was no difficulty in making the receiving operator understand even if the transmitting operator stood anywhere in the room at a distance of twenty feet or more from the transmitting instrument. The effect of the inductance coils properly distributed over the cable upon the efficiency of transmission astonishes even one like myself who have now worked for years upon and made myself perfectly familiar with this fascinating problem of Electro-Mechanics.

The inductance coils which I have so far described contain no iron. Coils with iron cores to be used for this purpose will have, of course, to be constructed in a perfectly definite way to work satisfactorily. I expect to bring this matter before the INSTITUTE at some future time. Suffice it to state now that such coils would be required in the construction of non-uniform submarine and underground telephone cables on account of the much smaller volume per unit of inductance. For long distance air lines inductance coils without iron cores would be in many respects preferable.

In conclusion I wish to thank my assistant Mr. Cushman, and my students, Mr. Frank and Mr. Koscherak for the very faithful and persevering way in which they have assisted me throughout these experimental researches.

Laboratory for Electro-Mechanics,
Columbia University,
New York.

PART II.[1]

WAVE PROPAGATION OVER NON-UNIFORM ELECTRICAL CONDUCTORS.

INTRODUCTION.

The main object of the mathematical theory developed in this paper is the analysis of the propagation of electrical waves over a conductor represented in Fig. 3, Sec. III. This conductor consists of a loop of wire, $L_1 \ldots . L_{k+1}$ of length $2l$, in which there are at equi-distant points, the so-called reactance points, a certain number of equal coils interposed dividing the loop into a number of equal parts, called the *interstices* of the loop. These coils may have condensers in series with them, or they may have secondary circuits with condensers. The propagation of electrical waves over a periodically loaded loop of this kind is compared to that over a uniform loop having the same total inductance, resistance, and capacity. This uniform loop is called "*the corresponding uniform conductor*" of the periodically loaded loop.

A similar problem in Mechanics is that of forced and of free vibrations of a periodically loaded heavy, flexible, inextensible string of finite length taking frictional resistance into account. To my knowledge, neither the electrical problem nor its corresponding mechanical problem have been investigated before.

It will be observed in the course of this paper that a study of the propagation of electrical waves over a periodically loaded conductor of this kind suggests forcibly an electromagnetic theory of emission and absorption of light by molecular complexes, which, on account of the physical conception underlying it. if for no other reason, possesses many attractive features. In this theory the ether and the material ions imbedded in it correspond to the uniform wire and the reactance points considered in this paper. These matters, however, are of a more or less speculative character, and have, therefore, no place here. But it should be noted that the physical problem discussed here was first suggested by speculations of this kind. It can be stated as follows: Under what conditions will the non-uniform conductor repre-

---

[1] Reprint from the *Transactions* of the American Mathematical Society, Vol. I.

sented in Fig. 3 be approximately equivalent to its corresponding uniform conductor? Or, to be more precise: For what frequencies will an electrical wave have approximately the same wave length and the same damping or attenuation constant on one conductor as on the other?

The mathematical theory developed here gives a definite answer to this question. This answer can be stated in a few words, and for that purpose it is desirable to introduce here a convenient technical term, the so-called *angular distance* of the interstices—that is, of the intervals between consecutive reactance points. This interval is at any given frequency a definite fraction of the wave length corresponding to that frequency. Let this fraction be $\varphi/2\pi$; then φ is the angular distance of the interstices. The angular distance of a wave length is, of course, 2π. The general rule expressing the conditions of equivalence of a non-uniform conductor to its corresponding uniform conductor can now be expressed as follows: *For any given frequency a non-uniform conductor of the second type is equivalent to its corresponding uniform conductor as nearly as* $\sin \varphi/2$ *is to* $\varphi/2$ *itself.*

The higher the frequency the less resemblance will there be between a given non-uniform conductor and its corresponding uniform conductor. Conversely, if this resemblance is sufficiently close for a given frequency, it will be closer for all lower frequencies. When the half-wave length under consideration becomes smaller than the interstices, then the resemblance as far as that wave length and all shorter wave lengths are concerned ceases altogether.

A brief summary of this mathematical paper will be given now.

The main object of this research is the solution of the problem of Section III. This solution depends on the solution of the problem of Section II, and this again is moulded after the pattern of the solution of the problem of Section I.

In Section I the wave propagation over a uniform wire conductor represented in Fig. 1 is discussed. The effect of the transmitting apparatus *A* and of the receiving apparatus *B* is taken into account. Equation [5] is the most general solution of this case. The propagation of waves of both forced and of free periods is easily deduced from it. This particular form of the general solution is new, and it was selected because it is best suited for comparing the propagation of waves over non-uniform conductors of Sections II and III to that over their corresponding uniform conductors.

In Section II the wave propagation over a non-uniform conductor of the first type represented in Fig. 2 is discussed. This conductor consists of a certain number of equal coils, $L_1 \ldots \ldots \ldots \ldots \ldots L_n$, which are connected in series. A certain number of equal condensers, one at each juncture between two consecutive coils, connect this conductor to ground. A transmitting apparatus A and a receiving apparatus B are present. The general solution of this problem, equation (6a), is moulded after the pattern of equation (5) of Section I. Both forced and free oscillations on a conductor of this kind are considered, and the conditions under which it becomes equivalent to its corresponding uniform conductor are worked out at considerable length. The problem of this section and its solution are both new.

The problem of Section III can, from a purely mathematical point of view, be stated as follows: Find the integral of the following partial differential equation:

$$L\,\frac{d^2 y}{dt^2} + R\,\frac{d\,y}{dt} = \frac{1}{C}\,\frac{\partial^2 y}{\partial s^2}$$

and determine it in such a way as to satisfy $k+2$ boundary conditions. Determine also the conditions under which this integral will be equivalent to the integral represented in equation (5), Sec. I.

Equation (2) represents the most general solution, and the constants $x_1\ x_2 \ldots \ldots \ldots \ldots \ldots x_{k+2}$ have to be determined from the $k+2$ boundary conditions. The principal mathematical difficulty here reduces itself, then, to the proper mathematical formulation of these boundary conditions so as to obtain a system of equations which can be readily solved. Such a system is system (3) of this section. It is of the same form as system (6) of Section II, the solution of which was obtained in that section. Equations (4) and (5) are thus obtained. Equation (5) is the most general solution, and when this equation becomes very nearly the same as equation (5) of Section I, then the non-uniform conductor of this section becomes equivalent to its corresponding uniform conductor. This equivalence cannot be decided without a careful study of the wave lengths and the damping constants of waves of different periods. This study is recorded in the remaining portion of this section. This section is also entirely new.

Sec. I and a part of Sec. II, together with a description of experimental investigations bearing upon the same, were published in Vol. XVI of the Transactions of the American Institute of Electrical Engineers for 1899. Additional experimental investigations bearing upon the principal problem—that is, the problem of Sec. III, will be published in the near future.

SECTION I

WAVE PROPAGATION OVER A UNIFORM LINEAR CONDUCTOR.

A.—Waves of Forced Period.

The conductor is a loop of wire A, B, (Fig. 1.) At one point of the loop is a transmitting apparatus A, at the opposite point is a receiving apparatus B. The distance between A and B is l, equal to one-half the length of the whole loop. The distance of any element $d\,s$ from A is s.

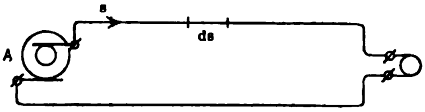


Fig. 1.

Let L, R, C, denote the inductance, resistance and capacity, respectively, per unit length. Let y be the current at any point s. Then

$$L\frac{d^2 y}{dt^2} + R\frac{d\,y}{dt} = \frac{1}{C}\frac{\partial^2 y}{\partial\, s^2} \qquad (1)$$

is the well known equation of propagation.

To formulate the two boundary conditions, one at the receiving and the other at the transmitting apparatus, let L_0, R_0, C_0, and L_1, R_1, C_1, be the inductance, resistance, and capacity, respectively, of the transmitting and of the receiving apparatus. Each contains a condenser in series with its inductance and resistance. Let the E. M. F. impressed by A be of type $E\,e^{ipt}$. The boundary equations can now be expressed as follows:

$$
(2)\quad \begin{cases} -2\left(\dfrac{\partial y}{\partial s}\right)_{s=o} = \left[D_0 - h_0\, y\right]_{s=o} & \text{at transmitting apparatus.} \\ +2\left(\dfrac{\partial y}{\partial s}\right)_{s=l} = -\left(h_1\, y\right)_{s=l} & \text{at receiving apparatus.} \end{cases}
$$

where

$$D_0 = ip\; C\, E\, e^{ipt}$$

$$h_0 = C\,(-p^2\,\lambda_0 + i\,p\,R_0),\; h_1 = C\,(-p^2\,\lambda_1 + i\,p\,R_1)$$

$$\lambda_0 = L_0 - \frac{1}{p^2\,C_0},\quad \lambda_1 = L_1 - \frac{1}{p^2\,C_1}$$

The physical character of the problem suggests the following solution :

$$y = K_1 \cos \mu\, \xi + K_2 \sin \mu\, \xi, \tag{3}$$

where $\xi = l - s$, and K_1 and K_2 are proportional to e^{ipt}.

Equation (1) is satisfied for all values of K_1 and K_2 if

$$C\,(-p^2\,L + i\,p\,R) = -\mu^2 = -(\alpha + i\,\beta)^2$$

From this we get

$$
\begin{aligned}
\alpha &= \sqrt{\tfrac{1}{2}\,p\; C\,[\,\sqrt{p^2\,L^2 + R^2} + p\,L]} \\
\beta &= \sqrt{\tfrac{1}{2}\,p\; C\,[\,\sqrt{p^2\,L^2 + R^2} - p\;L]}
\end{aligned}
\tag{4}
$$

When $p\;L$ is large in comparison to R,

$$\alpha = p\;\sqrt{L\,C},\quad \beta = \frac{R}{2}\sqrt{\frac{C}{L}}.^{*} \tag{4a}$$

The boundary equations will be satisfied if

$$K_1 = \frac{2\,\mu\,D_0}{F},\qquad K_2 = \frac{h_1\,D_0}{F},$$

where $\quad F = (h_0\,h_1 - 4\,\mu^2)\sin \mu\, l + 2\,\mu\,(h_0 + h_1)\cos \mu\, l$

---

* Observe that in the case of a twin conductor where the mutual capacity alone is considered, we must use 2 R and 2 L in place of R and L.

Hence (3) can now be written

$$y = (2\,\mu \cos \mu\,\xi + h_1 \sin \mu\,\xi)\,\frac{D_0}{F} \tag{5}$$

When $h_0 = h_1 = 0$

$$y = -\,\frac{D_0 \cos \mu\,\xi}{2\,\mu \sin \mu\,l} \tag{5a}$$

Equation (5) is a complete solution for the propagation of waves of forced period. It represents simple harmonic damped waves. The most essential elements which enter into the description of such waves are the *wave length* λ and the *damping* or *attenuation factor*. These can easily be calculated. Since $\mu = a + i\,\beta$, we shall have $\lambda = 2\,\pi/a$; the attenuation factor is $e^{-\beta\xi}$

It is evident that β diminishes as L increases. A high inductance per unit length means small attenuation and a slow speed of propagation.

B.—Waves With a Natural Period.

Free oscillations are readily calculated for a few special cases. Equation (5) is a general solution for free oscillations also, provided, however, that μ has such a value as to make

$$F = 0, \text{ since } D_0 = 0;$$

that is, we must have

$$(h_0\,h_1 - 4\,\mu^2) \sin \mu\,l + 2\,\mu\,(h_0 + h_1) \cos \mu\,l = 0, \tag{6}$$

but of course, in this case,

$$h_0 = k\;C(k\,\lambda_0 + R_0),\; h_1 = k\;C(k\,\lambda_1 + R\,),\; -\mu^2 = k\;C(k\;L + R).$$

Equation (6) is a transcendental equation and can be readily solved in a few simple cases.

Case 1.—The transmitting and receiving apparatus are not present. In this case $h_0 = h_1 = 0$. Equation (6) reduces to $\sin \mu\,l = 0$, therefore $\mu = s\,\pi/l$, where s can have any integer value from 1 to ∞. The periods of free oscillations are calculated from the equation

$$-\,\mu^2 = k^2\,L\,C + k\,R\,C = -\,\frac{s^2\,\pi^2}{l^2}.$$

Therefore

$$k = -\frac{R}{2L} \pm \sqrt{-1}\sqrt{\frac{1}{LC}\frac{s^2\pi^2}{l^2} - \frac{R^2}{4L^2}}$$

$$= -\frac{R}{2L} \pm i\,k_s.$$

There are, therefore, an infinite number of periods which are harmonically related to each other unless the damping constant $R/2L$ is not negligibly small in comparison with $\pi^2/l^2 LC$. The most general solution of this case can be written

$$y = e^{-\frac{Rt}{2L}} \sum_{s=1}^{\infty} A_s \cos\left(\frac{s\pi}{l}\xi\right)\cos\left(k_s t - \varepsilon_s\right) \qquad (7)$$

The wave lengths are

$$\frac{2l}{1},\ \frac{2l}{2},\ \frac{2l}{3},\ \ldots\ldots\ldots\ \frac{2l}{s},\ \ldots\ldots\ldots$$

CASE 2.—Transmitting apparatus is not present, and in place of the receiving apparatus there is a break in the wire.

In this case $h_0 = 0$, $h_1 = \infty$. Equation (6) reduces to

$$\cos\mu l = 0.$$

Therefore

$$\mu = \frac{2s+1}{l}\frac{\pi}{2},$$

$$k = -\frac{R}{2L} \pm i\sqrt{\frac{1}{LC}\left(\frac{2s+1}{l}\frac{\pi}{2}\right)^2 - \frac{R^2}{4L^2}}$$

$$= -\frac{R}{2L} \pm i\,k_{2s+1},$$

$$y = e^{-\frac{Rt}{2L}} {}_{s}\sum_{0}^{\infty} A_{2s+1}\sin\left(\frac{2s+1}{l}\frac{\pi}{2}\xi\right)\cos\left(k_{2s+1} - \varepsilon_{2s+1}\right)$$

$$(8)$$

The wave lengths are $\frac{4l}{1},\ \frac{4l}{3},\ \frac{4l}{5},\ \ldots\ldots\ldots$

The damping factor is in both cases the same for all frequencies, hence the color of the complex harmonic vibration remains unchanged during the whole epoch of its existence.

SECTION II.

ELECTRICAL OSCILLATIONS ON A NON-UNIFORM CONDUCTOR OF THE FIRST TYPE.

The conductor consists of 2 n equal coils L_1, L_2...L_n (Fig. 2) connected in series, so as to form a closed loop. At one point A of this loop is an alternator, at the opposite point is a receiving apparatus, B. At equal distances 2 (n — 1) equal condensers, C_1........C_{n-1}, connect the conductor to ground.

The whole loop is thus divided into 2 n—2 component circuits 1, 2........2 n — 2. It is evident that in the limit when n becomes infinitely large, this conductor becomes an ordinary telegraph or telephone line with uniformly distributed resistance, capacity, and inductance. The question arises now, under what conditions will a conductor of this kind become equivalent with sufficient approximation to a uniform line, even when n is not infinitely large? This problem does not seem to have been solved before.

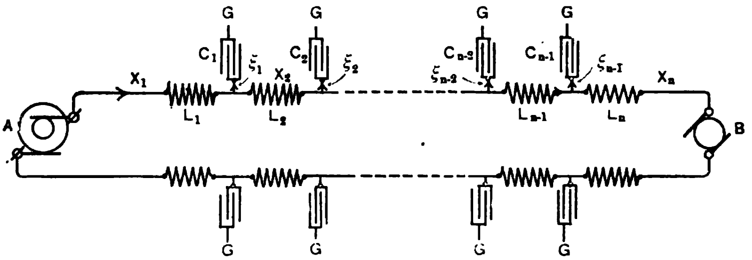


FIG. 2.

In its main features it is similar to that which Lagrange solved in his "Mecanique Analytique, sec. partie, Sec. VI," the problem, namely, of the free vibrations of a weightless string, fixed at its two ends and loaded at equi-distant points by equal weights. But it is much more general, because frictional resistances are taken into consideration, and also because forced as well as free oscillations are considered.

Let L_0, R_0, C_0, and L_1, R_1 and C_1, be the inductance, ohmic resistance, and capacity of A and B, respectively. Let L, R, C, be the corresponding quantities of the coils and condensers in the several component circuits.

The real part of $E e^{ipt}$ is the E.M.F. impressed by alternator A. Let x_1........x_n be the currents in the component circuits.

$P_1 \ldots\ldots P_{n-1}$ are the differences of potential in the line condensers, C_1, $C_2 \ldots\ldots C_{n-1}$; P_0 and P^1 are the differences of potential in the condensers in A and B, respectively; $\xi_1 \ldots\ldots\ldots \xi_{n-1}$ are the condenser currents. We shall have

$$\left.\begin{array}{ll} \xi_1 = C\dfrac{d\,P_1}{dt}, & \xi_2 = C\dfrac{d\,P_2}{dt}, \ldots\ldots \text{etc.} \\[2ex] \xi_1 = x_1 - x_2, & \xi_2 = x_2 - x_3, \ldots\ldots \text{etc.} \end{array}\right. \qquad (1)$$

A.—Forced Oscillations.

Stating the law of equality of action and reaction for each component circuit we obtain the following n differential equations:

$$\left.\begin{array}{c} (L_0 + 2\,L)\dfrac{d\,x_1}{dt} + (R_0 + 2\,R)\,x_1 + 2\,P_1 + P_0 = E\,e^{ipt}, \\[2ex] L\,\dfrac{d\,x_2}{dt} + R\,x_2 + P_2 - P_1 = 0, \\[2ex] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\[2ex] L\,\dfrac{d\,x_{n-1}}{dt} + R\,x_{n-1} + P_{n-1} - P_{n-2} = 0, \\[2ex] (L_1 + 2\,L)\dfrac{d\,x_n}{dt} + (R_1 + 2\,R)\,x_n - 2\,P_{n-1} + P^1 = 0. \end{array}\right\} \quad (2)$$

When the steady state has been reached, the currents will be just like the impressed E. M. F., simple harmonics of the time t, that is,

$$x_1 = A_1\,e^{ipt}, \quad x_2 = A_2\,e^{ipt}, \qquad (3)$$

where A_1, $A_2 \ldots\ldots\ldots$ are complex quantities.

Differentiating each member of (2) and substituting from (3) and (1), we obtain

$$\left.\begin{array}{l} h\,x_1 + \xi_1 \quad - 0 \quad\ = D, \\[1ex] h\,x_2 + \xi_2 \quad - \xi_1 \quad = 0, \\[1ex] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\[1ex] h\,x_{n-1} + \xi_{n-1} - \xi_{n-2} = 0, \\[1ex] h\,x_n + 0 \quad - \xi_{n-1} = -\,h_1\,x_n, \end{array}\right\} \quad (4)$$

where $$h = C\,(-p^2\,L + i\,p\,R),$$

$$D = \tfrac{1}{2}\,i\,p\,C\,E\,e^{ipt} - \tfrac{1}{2}\,C\,(-p^2\,\lambda_0 + i\,p\,R_0) = D_0 - h_0\,x_1,$$

$$h_1 = \tfrac{1}{2}\,C\,[-p^2\,\lambda_1 + i\,p\,R_1],$$

$$\lambda_0 = L_0 - \frac{1}{p^2\,C_0}, \qquad \lambda_1 = L_1 - \frac{1}{p^2\,C_1}.$$

Another form is obtained by substituting for ξ_1, ξ_2........as follows:

$$\left.\begin{array}{l} (h+1)\,x_1 + 0 - x_2 = D = D_0 - h_0\,x_1 \\ (h+2)\,x_2 - x_1 - x_3 = 0 \\ \ldots\ldots\ldots\ldots\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ (h+2)\,x_{n-1} - x_{n-2} - x_n = 0 \\ (h+1)\,x_n - x_{n-1} - 0 = -h_1\,x_n. \end{array}\right\} \quad (6)$$

Equation (3) of Sec. 1 suggests the following solution:

$$x_m = K_1 \cos 2\,(n-m)\,\theta + K_2 \sin 2\,(n-m)\,\theta \quad [6a]$$

If $h + 2 = 2 \cos 2\,\theta$ then all the equations except the first and the last will be satisfied for all values of K_1 and K_2. These two equations, which correspond to the boundary equations of Sec. 1., will be also satisfied if we assign to K_1 and K_2 suitable values, as follows:

$$K_2 = \frac{(h_1 - 1) + \cos 2\,\theta}{\sin 2\,\theta} \quad K_1$$

$$K_1 = \frac{D_0 \sin 2\,\theta}{h_0\,h_1 \sin 2\,(n-1)\,\theta - 4 \sin^2\theta \sin 2n\,\theta + 2(h_0+h_1)\sin\theta\cos(2n-1)\theta}$$

we can now write, (7)

$$x_m = \frac{[2 \sin\theta \cos(2\,n - 2\,m + 1)\,\theta + h_1 \sin 2\,(n-m)\,\theta]\;D_0}{h_0 h_1 \sin 2(n-1)\theta - 4 \sin\theta \sin 2\,n\theta + 2(h_0+h_1)\sin\theta \cos(2n-1)\theta}$$

θ is a complex angle, hence the forced oscillations of type e^{ipt} on a non-uniform conductor of this kind are simple harmonic damped oscillations. The similarity between this conductor and a uniform wire will be discussed presently. When $h_0 = h_1 = o$ we obtain

$$x_m = \frac{-D_0 \cos(2\,n - 2\,m + 1)\,\theta}{2 \sin\,\theta \sin\,2\,n\,\theta} \qquad (7a)$$

B.—Free Oscillations.

Equation (7) holds true for free as well as for forced oscillations. But since in the case of free oscillations $D_0 = o$ it follows that the denominator of (7) must vanish to prevent the vanishing of all currents. We shall have, therefore,

$$h_0 \, h_1 \sin (2\,n - 2)\,\theta - 4 \sin^2 \theta \sin 2\,n\,\theta + \\ + 2\,(h_0 + h_1) \sin \theta \cos (2\,n - 1)\,\theta = o \qquad (8)$$

From this equation θ and the corresponding periods and damping constants have to be determined. A solution can be readily obtained for a small number of cases. The two most important will be considered here.

First.—The transmitting and the receiving apparatus are not present. In this case $h_0 = h_1 = o$, and

$$x_m = B \cos (2\,n - 2\,m + 1)\,\theta \qquad (9)$$

It is found from (8) that (9) is actually the solution of the differential equations (6) for $h_0 = h_1 = D_0 = 0$, provided that $\theta = \frac{s\,\pi}{2\,n}$, where s is any integer from 1 to 2 n.

Hence the most general solution will be

$$x_m = \sum_{s=1}^{2n} B_s \cos (2\,n - 2\,m + 1)\,\frac{s\,\pi}{2\,n} \qquad (10)$$

But it should be observed now that x_m is a periodic function of the time, that is

$$x_m = \sum_{s=1}^{\infty} K_s \, e^{p_s t}$$

Hence in (10) each amplitude B contains the time factor e^{pt}.

The constant p_s which measures the period and the damping constant of the free oscillation is determined from the relation:

$$h = -4 \sin^2 \theta.$$

In the case of free oscillations

$$h = p_s^2 \, L \, C + p_s \, R \, C, \theta = \frac{s\,\pi}{2\,n}.$$

Hence

$$p_s^2 \, L \, C + p_s \, R \, C = - 4 \sin^2 \frac{s \, \pi}{2 \, n}. \tag{11}$$

Before solving this equation, it is desirable to make the following substitution:

Let $L,'$ $C,'$ R' be the total inductance, capacity, and resistance, respectively, of one-half of the conductor, then

$$L = \frac{L'}{n}, \quad C = \frac{C'}{n}, \quad R = \frac{R'}{n}.$$

Let l denote the half length of a uniform wire having σ, r, c, for inductance, resistance, and capacity per unit length, and let it have the same total inductance, resistance, and capacity as the non-uniform conductor. Since

$$l\sigma = L', \; lr = R', \; lc = C',$$

we shall have

$$L = \frac{l \, \sigma}{n}, \quad C = \frac{l \, c}{n}, \quad R = \frac{l \, r}{n}.$$

This uniform wire having the same total inductance, resistance, and capacity as the non-uniform conductor, will be called the "*corresponding uniform conductor.*"

From (11) we obtain

$$\frac{l^2}{n^2} \left(p_s^2 \, \sigma \, c + p_s \, c r \right) = - 4 \sin^2 \frac{s \, \pi}{2 n},$$

therefore

$$p_s = - \frac{r}{2 \, \sigma} \pm \sqrt{- 1} \sqrt{\frac{1}{\sigma \, c} \frac{4 \, n^2}{l^2} \sin^2 \frac{s \, \pi}{2 \, n} - \frac{r^2}{4 \sigma^2}},$$

$$p_s = \frac{r}{2 \, \sigma} \pm i \, k_s$$

Equation (10) becomes now:

$$x_m = e^{\frac{-r t}{2 \sigma}} \sum_{s=1}^{2 n} A_s \cos \left(2 \, n - 2 \, m + 1 \right) \frac{s \, \pi}{2 \, n} \cos \left(k_s \, t - \epsilon_s \right). \tag{12}$$

It is clear that the oscillations on the non-uniform conductor of type (1) have the same damping constant as the oscillations on the corresponding uniform conductor. It will be shown presently that under certain conditions they will also have the longer periods up to a certain limit very nearly the same as the corresponding uniform conductor. *For these periods, then, the non-uniform conductor will be equivalent to its corresponding uniform conductor.*

Second Case.—The transmitting apparatus is not present, and in place of the receiving apparatus there is a break in the line at B.

In this case $h_0 = 0$, $h_1 = \infty$. Equation (9) gives

$$x_m = B \sin (2n - m + 2)\,\theta,$$

provided that

$$\cos (2n - 1)\,\theta = o,$$

or

$$\theta = \frac{2s+1}{2n-1}\,\frac{\pi}{2}.$$

We shall have, therefore,

$$p_{2s+1} = \frac{-r}{2\sigma} \pm i \sqrt{\frac{1}{\sigma c}\,\frac{4n^2}{l^2} \sin^2 \frac{2s+1}{2n-1}\,\frac{\pi}{2} - \frac{r^2}{4\sigma^2}}$$

$$= -\frac{r}{2\sigma} \pm i\, k_{2s+1}$$

Hence

$$x_m = e^{-\frac{rt}{2\sigma}} \sum_{s=0}^{2n} A_{2s+1} \sin (2n - 2m + 2)\,\frac{2s+1}{2n-1}\,\frac{\pi}{2}$$

$$\cos (k_{2s+1} t - \varepsilon_{2s+1}). \quad (13)$$

The same remark regarding the damping constant and the free periods applies here as in the preceding case.

THE WAVE LENGTHS OF FREE OSCILLATIONS.

The angles $s\pi/2n$ and $(2s + 1)\,\pi/2\,(2n - 1)$ have an interesting physical meaning which will be brought out by considering the wave-lengths of free oscillations. Consider one of the component harmonics of x_m in Case I, say

$$\xi_{m,s} = A_s \cos (2n - 2m + 1)\, s\pi/2n \cos (k_s t - \epsilon_s).$$

Compare it to the corresponding component of x_{m_1}, that is to

$$\xi_{m_1,s} = A_s \cos (2n - 2m_1 + 1)\, s\pi/2n \cos (k_s t - \epsilon_s).$$

If they are a wave length apart, $\xi_{m,s} = \xi_{m_1,s}$ and $m_1 - m =$ number of coils covered by one wave length. But in this case

$$(2n - 2m + 1)\, s\pi/2n = (2n - 2m_1 + 1)\, s\pi/2n + 2\pi,$$

therefore $\qquad m_1 - m = 2n/s = \nu_s.$

$\nu_s = 2n/s$ is, therefore, the number of coils covered by a wave length which corresponds to the harmonic s. It can be shown that in the second case

$$\frac{2(2n - 1)}{2s + 1} = \nu_s$$

For $\frac{s\pi}{2n}$ and $\frac{2s+1}{2n-1}\frac{\pi}{2}$ we can, therefore, write $\frac{\pi}{\nu_s} = \frac{1}{2}\frac{2\pi}{\nu_s}$

The physical meaning of $2\pi/\nu_s$ can now be readily fixed. A coil represents a definite fraction of a wave length, and this fraction will have a different value for different harmonics. The higher the harmonic the shorter will be the wave length, and therefore the larger will be the value of this fraction. It is convenient, however, to measure this fraction in terms of an angle instead of in terms of a wave length. If we arbitrarily assume that an angular distance 2π corresponds to a wave length, then an angular distance $2\pi/n$ will correspond to the nth part of a wave length. With this understanding

$$\frac{s\pi}{2n} \text{ and } \frac{2s+1}{2n-1}\frac{\pi}{2}, \text{ that is, } \frac{1}{2}\frac{2\pi}{\nu_s}$$

represents one-half of the angular distance covered by a coil.

A NON-UNIFORM CONDUCTOR OF THE FIRST TYPE COMPARED TO ITS CORRESPONDING UNIFORM WIRE.

a.—SIMILARITY WITH RESPECT TO FREE OSCILLATIONS.

Comparing the expressions for the free periods of oscillation which were obtained in Sections I and II we see that as long as π/ν_s can be written for $\sin \pi/\nu_s$ so long will the periods of free oscillations of the non-uniform conductor be nearly the same as those of its corresponding uniform conductor. We have, therefore, the simple rule: *A non-uniform conductor of the first type represents its corresponding uniform conductor as nearly as one-half of the angular distance covered by one of its coils represents the sine of that distance.* The non-uniform conductor employed by me[1] in my experiments had 400 coils. In this case

$$\frac{\pi}{\nu_s} = \frac{s\,\pi}{400}$$

For $s = 25$ we have $\pi\ \nu_s = \pi/16$. Now, $\sin \pi/16$ differs from $\pi/16$ by $\frac{3}{8}$ of one per cent. of the value of $\pi/16$. Hence, the period of the 25th harmonic of my non-uniform conductor differs from that of the same harmonic on the corresponding uniform wire by less than $\frac{3}{8}$ of one per cent. For lower harmonics the difference is smaller. The 25th harmonic had approximately 3500 P.P.S. Hence, up to the 25th harmonic—that is, up to 3500 P.P.S.—the non-uniform conductor employed by me had nearly the same free periods as its corresponding uniform conductor.

b.—Similarity With Respect to Forced Oscillations.

The wave length and the attenuation constant corresponding to a given frequency speed p_s can be studied by studying the angle θ from the following equation:

$$-4 \sin^2\theta_s = -p_s^2\, L\, C + i p_s\, R\, C = \frac{l^2}{n^2}[-p_s^2\, \sigma\, C + i p_s\, r\, C]$$

$$= -\frac{l^2}{n^2}\mu_s^2 = -\frac{l^2}{n^2}\ (a_s + i\,\beta_s)^2 \text{ or } \sin\theta_s = \tfrac{1}{2}\frac{l}{n}\,(a_s + i\,\beta_s)$$

where σ, c, r are the inductance, capacity and resistance, respectively, per unit length of the corresponding uniform conductor; μ_s, a_s and β_s have the same meaning as in Sec. I.

Referring now to equation (4) Sec. I, it will be found that

$$a_s \geqq \beta_s.$$

---

[1] See paper cited in the introduction.

If, therefore, $\frac{1}{2}\alpha_s/2n$ is sufficiently small then we can put

$$\theta_s = \tfrac{1}{2}\frac{l}{n}(\alpha_s + i\beta_s) = \tfrac{1}{2}\frac{l}{n}\mu_s.$$

When this substitution is made in (7) and (7^a) these equations will transform into (5) and (5^a) of Sec. I, which shows that under these conditions the non-uniform conductor of the first type becomes approximately equivalent to its corresponding uniform conductor, the degree of approximation being the same as the degree of equality between sin θ_s and θ_s.

The physical meaning of this can be readily made clear. If by λ_s we denote the wave length on the corresponding uniform conductor corresponding to the frequency speed p_s, then according to Sec. I,

$$\alpha_s = \frac{2\pi}{\lambda_s}, \quad \frac{l}{n}\alpha_s = \frac{l}{n}\frac{2\pi}{\lambda_s}.$$

Let n_s be the number of coils on the non-uniform conductor which cover a wave length of frequency speed p_s, and let φ_s be the angular distance covered by a coil, then

$$\varphi_s = \frac{2\pi}{n_s}.$$

Again $$n : n_s :: l : \lambda_s,$$

or $$n : \frac{2\pi}{\varphi_s} :: l : \lambda_s.$$

Hence $$\frac{l}{n}\frac{2\pi}{\lambda_s} = \frac{l}{n}\alpha_s = \varphi_s$$

The substitution mentioned above will therefore be permissible when $\frac{1}{2}\varphi_s$ (that is, one-half of the angular distance covered by a coil) is approximately equal to sin $\varphi_s/2$.

We have here the same rule as in the case of free oscillations. It will be shown in the next section that this rule is also applicable to non-uniform conductors of the second type for waves of both forced and of free periods.

SECTION III.

WAVE PROPAGATION OVER A NON-UNIFORM CONDUCTOR OF THE SECOND TYPE.

A. WAVES OF FORCED PERIOD.

Such a conductor is represented in diagram of Fig. 3. A long, uniform wire forms a loop $L_1 \ldots . L_{k+2}$. At equal intervals are inserted in series $2\,k + 2$ equal coils $L_1\, L_2 \ldots .$ To make the discussion more general, let each coil have a condenser of capacity C_0 in series with it.

Let L, R, C represent the inductance, resistance, and capacity, respectively, per unit length of the uniform wire. Let an E. M. F. of type $E e^{ipt}$ be impressed at L. Employing the usual notation we shall have the following equation of propagation at every point of the uniform wire:

$$L \frac{d^2 y}{d t^2} + R \frac{d\, y}{d t} = \frac{1}{C} \frac{\partial^2 y}{\partial\, s^2} \tag{1}$$

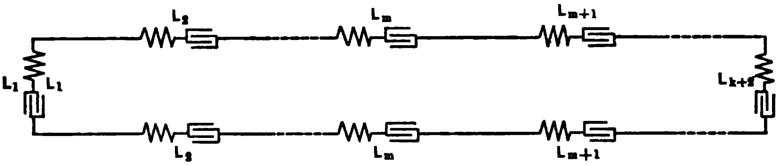


FIG. 3.

The same as in Sec. I, but here the integral has to satisfy 2 k + 2 boundary conditions, one at each coil. On account of the symmetry of distribution of the coils on the two sides of the loop this number is reduced to k + 2.

To formulate these boundary conditions introduce the following notation:

Let $2\,l$ = length of loop; $l/(k+1)$ will be the distance between two consecutive coils. Let L_0, R_0, C_0 be the inductance, resistance and capacity, respectively, of each coil. Let y_m be the current at any point of the interval between coils L_m and L_{m+1}. Denote the distance of this point from coil L_m by ξ.

The currents in the coils will be denoted by x_1 x_2 x_{k+1} x_{k+2} It is evident that

$$(y_m)_{\xi=0} = (y_{m-1})_{\xi=l/k+1} = x_m .$$

The boundary conditions for all coils except L_1 and L_{k+2} can now be stated.

$$\left(\frac{\partial y_{m-1}}{\partial \xi}\right)_{\xi=l/k+1} - \left(\frac{\partial y_m}{\partial \xi}\right)_{\xi=0} =$$

$$= - C(-p^2 \lambda_0 + i\,p\,R_0)\,x_m = -h\,x_m,$$

where $$\lambda_0 = L_0 - \frac{1}{p^2 C_0}.$$

There are k equations of this form. The boundary equations for the first and the last coil are of the following form:

$$-2\left(\frac{\partial y_1}{\partial \xi}\right)_{\xi=0} = i\,p\,C\,E\,e^{ipt} - h\,x_1 = D - h\,x_1$$

for the first coil, and

$$2\left(\frac{\partial y_{k+1}}{\partial \xi}\right)_{\xi=l/k+1} = -h\,x_{k+2}$$

for the last coil.

Equation (3) of Sec. I and equation (6a) of Sec. II suggest the following solution:

$$y_m = K_1 \cos \mu\,\xi + K_2 \sin \mu\,\xi, \qquad (1a$$

where μ has the same value as in Sec. I.
When $\xi = 0$, y_m becomes x_m, and when $\xi = l/k+1$, y_m becomes x_{m+1}.

Hence

$$x_m = K_1,\ x_{m+1} = K_1 \cos\frac{\mu\,l}{k+1} + K_2 \sin\frac{\mu\,l}{k+1}.$$

Therefore

$$y_m = \frac{x_m \sin \mu\left(\frac{l}{k+1} - \xi\right) + x_{m+1} \sin \mu\,\xi}{\sin\frac{\mu\,l}{k+1}} \qquad (2)$$

We have now to determine the $k+2$ constants $x_1\,x_2 \ldots . x_{k+2}$

from the k + 2 boundary equations. Begin with the boundary equation at the coil L_1:

$$\frac{\partial y_m}{\partial \xi} = \frac{\mu \left[- x_m \cos \mu \left(\frac{l}{k+1} - \xi\right) + x_{m+1} \cos \mu \xi\right]}{\sin \frac{\mu l}{k+1}}$$

Therefore

$$-2\left(\frac{\partial y_1}{\partial \xi}\right)_{\xi=0} = 2\left(x_1 \cos \frac{\mu l}{k+1} - x_2\right) \frac{\mu}{\sin \frac{\mu l}{k+1}} = D - hx$$

$$\text{Let } \sigma = h\,\frac{\sin \frac{\mu l}{k+1}}{\mu} - 4 \sin^2 \frac{1}{2}\,\frac{\mu l}{k+1},$$

$$\rho = \frac{\sin \frac{\mu l}{k+1}}{\mu}\,D;$$

This boundary equation can then be written:

$$\left.\begin{array}{ll}
 & (\sigma + 1)\,x_1 - 0 - x_2 = \frac{\rho}{2} + \frac{\sigma}{2}\,x_1 \\
\text{Similarly} & (\sigma + 2)\,x_2 - x_1 - x_3 = 0 \\
 & (\sigma + 2)\,x_3 - x_2 - x_4 = 0 \\
 & \ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
 & (\sigma + 2)\,x_m - x_{m-1} - x_{m+1} = 0 \\
 & \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
 & (\sigma + 2)\,x_{k+1} - x_k - x_{k+2} = 0 \\
 & (\sigma + 1)\,x_{k+2} - x_{k+1} - 0 = \frac{\sigma}{2}\,x_{k+2}
\end{array}\right\} (3)$$

This system is of the same form as system (6) of Sec. II. Equation (7) of that section enables us to write down the solution of (3).

Let $\sigma + 2 = 2 \cos 2 \psi$

then

$$x_m = -\frac{D \sin \frac{\mu l}{k+1} \cos 2(k - m + 2)\psi}{2 \mu \sin 2\psi \sin 2(k+1)\psi} \tag{4}$$

$$y_m = -\frac{\left[\cos 2(k-m+2)\psi \sin \mu\left(\frac{l}{k+1} - \xi\right) + \cos 2(k-m+1)\psi \sin \mu\xi\right] D}{2 \mu \sin 2\psi \sin 2(k+1)\psi} \tag{5}$$

These equations give the complete mathematical representation of waves of forced period on a conductor of this kind. φ and μ are, of course; complex angles; hence, in order to calculate from these equations in any particular case the principal quantities with which we are concerned in wave propagation, namely, the wave length and the attenuation constant, it would be necessary to study separately the real and the imaginary parts of these equations. This study in its broadest aspect presents considerable mathematical complexity. It is, however, somewhat remote from the principal aim of this paper, which is to ascertain the conditions under which a non-uniform conductor of the second type is approximately equivalent to its corresponding uniform conductor; that is to say, for what frequencies will the two have approximately the same wave lengths and the same attenuation constants?

EQUIVALENCE OF A NON-UNIFORM CONDUCTOR OF THE SECOND TYPE TO ITS CORRESPONDING UNIFORM CONDUCTOR.

An answer to this question is obtained by studying the following equation:

$$\frac{h_s \sin \frac{\mu_s l}{k+1}}{\mu_s} + 2 \cos \frac{\mu_s l}{k+1} = 2 \cos 2 \psi_s,$$

or

$$\frac{h_s \sin \frac{\mu_s l}{k+1}}{\mu_s} - 4 \sin^2 \tfrac{1}{2} \frac{\mu_s l}{k+1} = - 4 \sin^2 \psi_s$$

The subscript s denotes that the particular frequency speed p_s s considered.

$$\mu_s = \alpha_s + i \beta_s, \qquad \alpha_s \geqq \beta_s.$$

If λ_s is the wave length corresponding to p_s on the uniform wire before the introduction of the reactance points, then

$$\frac{l}{k+1}\,a_s = \frac{l}{k+1}\,\frac{2\,\pi}{\lambda_s}.$$

Let θ_s be the angular distance between two consecutive coils for wave length λ_s, then

$$2\pi\ :\ \lambda_s\ ::\ \theta_s\ :\ \frac{l}{k+1}$$

$$\therefore \qquad \theta_s = \frac{l}{k+1}\,\frac{2\,\pi}{\lambda_s} = \frac{l}{k+1}\,a_s$$

Hence, if θ_s is so small that $\sin\theta_s = \theta_s$ very nearly, then

$$\frac{l}{k+1}\,h_s - \left(\frac{l}{k+1}\right)^2 \mu_s^2 = -\,4\,\sin^2\psi_s$$

or

$$\left(\frac{l}{k+1}\right)^2 C\left[-\,p_s^2\,(\rho+L) + i\,p\,(r+R)\right] = -\,4\,\sin^2\psi_s$$

where ρ and r are the inductance and resistance, respectively, per unit length of the inserted coils, so that $\rho + L$ and $r + R$ are the inductance and resistance, respectively, of the corresponding uniform conductor. This last equation can also be written:

$$\tfrac{1}{2}\,\frac{l}{k+1}\,(a_s^1 + i\,\beta_s^1) = \sin\psi_s$$

In this case also $a_s^1 \geqq \beta_s^1$. Let λ_s^1 be the wave length for frequency speed p_s on the corresponding uniform conductor, then

$$a_s^1 = \frac{2\,\pi}{\lambda_s^1}.$$

Put $\varphi_s^1 = l\,a_s^1/(k+1)$ then φ_s^1 is the angular distance between two consecutive coils, the angular distance of λ_s^1 being $2\,\pi$.

If, therefore, $\tfrac{1}{2}\,\varphi_s^1$ is so small that $\sin\tfrac{1}{2}\,\varphi_s^1 = \tfrac{1}{2}\,\varphi_s^1$ very nearly, then

$$\psi_s = \tfrac{1}{2}\,\frac{l}{k+1}\,(a_s^1 + i\,\beta_s^1) = \tfrac{1}{2}\,\frac{l}{k+1}\,\mu_s^1,$$

very nearly.

Making this substitution in (4) we obtain equation (5*a*), Sec. I. The equation of wave propagation for a non-uniform conductor of the second type is under these conditions the same as that for its corresponding uniform conductor. The two will have approximately the same wave length and the same attenuation constant for the frequency speed p_s. *The degree of approximation is the same as the degree of approximation in the equality between*

$$\sin \varphi_s/2 \text{ and } \varphi_s/2.$$

A numerical example will illustrate this point more clearly.

Consider a uniform telegraph wire having the following constants per mile:

$$L = .004 \text{ henrys}$$
$$R = 7 \text{ ohms}$$
$$C = .01 \times 10^{-6} \text{ farads}$$

Introduce at each mile a coil having

$$L_1 = .036 \text{ henrys}$$
$$R_1 = 1 \text{ ohm}$$

The non-uniform conductor thus obtained will have for its corresponding uniform conductor a uniform wire having per mile

$$L + L_1 = .04 \text{ henrys}$$
$$R + R_1 = 8 \text{ ohms}$$
$$C = .01 \times 10^{-6} \text{ farads}$$

For a frequency of 1500 P.P.S. we shall have $p_s = 2\pi \times 1500$. The wave length λ_s^1 on this corresponding uniform conductor for frequency of 1500 P.P.S. is very nearly

$$\lambda_s^1 = 33 \text{ miles.}$$

Hence, since the interposed coils are one mile apart we shall have

$$\sin \tfrac{1}{2} \varphi^1 = \sin \pi/33.$$

Now, $\sin \pi/33 = \pi/33$ to within one-sixth of one per cent. of the value of $\pi/33$. Up to this degree of approximation will, then, the non-uniform conductor just described have the same wave length and the same attenuation constant as its corresponding uniform conductor. For lower frequencies the degree of approximation will be much higher; hence, for all frequencies which are of any importance in the telephonic transmission of speech the two conductors are equivalent.

B. Waves of Free Period.

Equation (4) holds for all values of D; it should therefore hold good when $D = O$. In this case, however, all the currents will vanish unless the denominator vanishes—that is, unless

$$\sin 2\,\psi \sin 2\,(\mathrm{k} + 1)\,\psi = 0 \ldots\ldots (4^a).$$

This transcendental equation, together with the equation

$$\frac{h}{\mu} \sin \frac{\mu\,l}{k+1} + 2 \cos \frac{\mu\,l}{k+1} = 2 \cos 2\,\psi \qquad (4b)$$

determines the free periods and their corresponding damping constants.

Equation ($4a$) will be fulfilled when

$$\psi = \frac{r\,\pi}{2\,(k+1)}$$

where r is any integer from 0 to ∞.

When $r = s\ (\mathrm{k} + 1)$ then we shall have not only

$$\sin 2\,(\mathrm{k} + 1)\,\psi = 0, \text{ but also } \sin 2\,\psi = 0.$$

These particular values of ψ give a set of free oscillations which form a distinct group, called further below the oscillations of *normal period.*

Equation ($4b$) should, therefore, be written:

$$\frac{h_r \sin \dfrac{\mu_r\,l}{k+1}}{\mu_r} + 2 \cos \frac{\mu_r\,l}{k+1} = 2 \cos \frac{r\,\pi}{k+1} \qquad (4c)$$

This equation will be referred to as the *period equation.*

It should be observed that

$$-\,\mu_r^2 = C\,(\nu_r^2\,L + \nu_r\,R), \quad h_r = C\,(\nu_r^2\,\lambda_0 + \nu_r\,R_0)$$

An inspection of (5) shows that the complete solution for waves of free period can now be written:

$$y_m = \sum_{r=1}^{\infty} \frac{A_r}{\sin \frac{r\pi}{k+1}} \left\{ \cos (k - m + 2) \frac{r\pi}{k+1} \sin \mu_r \left(\frac{l}{k+1} - \xi \right) + \right.$$

$$\left. \cos (k - m + 1) \frac{r\pi}{k+1} \sin \mu_r \xi \right\} = \sum_{r=1}^{\infty} \eta_r$$

In the case of a uniform wire the periods and the wave lengths of the simple harmonic components η_1 $\eta_2 \ldots\ldots \eta_r \ldots\ldots$ have in general a harmonic relation. The introduction of the reactance points L_1 $L_2 \ldots\ldots$ disturbs this relation in consequence of a displacement in the values of the normal periods and of the normal damping constant. It is evident from purely physical considerations that since the introduction of the reactance points increases in general the inductance per unit length the periods will be lengthened.

a. WAVES OF NORMAL PERIOD.

According to equation (7), Sec. I, the wave lengths of free oscillations on a uniform loop are as follows:

$$\frac{2l}{1} \quad \frac{2l}{2}, \quad \frac{2l}{3}, \ldots\ldots \frac{2l}{k+1}, \quad \frac{2l}{k+2}, \ldots\ldots \frac{2l}{2(k+1)}, \quad \frac{2l}{2(k+3)},$$

$$\ldots\ldots \frac{2l}{s(k+1)}, \quad \frac{2l}{s(k+1)+1} \ldots\ldots$$

Divide this series into groups of (k + 1) members each. Consider now the last member of each group; call it the *terminal member*. The wave lengths of the terminal members are

$$\frac{2l}{(k+1)}, \quad \frac{2l}{2(k+1)}, \ldots\ldots \frac{2l}{s(k+1)}, \ldots\ldots$$

These terminal members will appear with normal periods among the free oscillations on the periodically loaded loop. To show this, consider the components of y_m of type $\eta_{s(k+1)}$, where

s may be any integer between 1 and ∞. Since in the case of these components $\psi = s\pi$ the period equation becomes:

$$\frac{h}{\mu} \sin \frac{\mu l}{k+1} + 2 \cos \frac{\mu l}{k+1} = 2 \cos s\pi.$$

This equation will be satisfied by putting

$$\mu = \frac{(k+1)\, s\pi}{l}.$$

The free periods of components of type $\eta_{s(k+1)}$ are now easily obtained.

$$\nu_s^2 L C + \nu_s R C = -\mu^2 = -\frac{(k+1)^2 s^2 \pi^2}{l^2}$$

$$\therefore \qquad \nu_s = -\frac{R}{2L} \pm i \sqrt{\frac{1}{LC}\, \frac{(k+1)^2 s^2 \pi^2}{l^2} - \frac{R^2}{4L^2}}$$

$$= -\frac{R}{2L} \pm i p_s.$$

From the expressions for y_m we deduce:

$$\eta_{s(k+1(} = B_{s(k+1)} \sin \frac{(k+1)\, s \pi \xi}{l},$$

where

$$B_{s(k+1)} = B^1_{s(k+1)}\, e^{-\frac{Rt}{2L}} \cos\left(p_{s(k+1)} t - \epsilon_{s(k+1)}\right).$$

The wave length of this component is $2l/s(\mathrm{k}+1)$.

The wave lengths of the components of type $\eta_{s(k+1)}$ are:

$$\frac{2l}{k+1}, \quad \frac{2l}{2(k+1)}, \quad \frac{2l}{3(k+1)}, \; \ldots \; \frac{2l}{s(k+1)} \; \ldots$$

From these wave lengths and their corresponding periods we see that the oscillations of the type $\eta_{s(k+1)}$ are identical with the terminal members of the groups into which the free oscillations on a uniform loop were divided above. The physical reason why these periods have not been disturbed by the introduction of reactance points is easily seen. It is because they have their nodes at the reactance points. The other k members of each group have been disturbed by the presence of the reactance points. The character of this disturbance will be now discussed.

b. WAVES OF DISPLACED PERIOD.

From the expression for y_m we deduce, by putting $\xi = 0$,

$$x_m = \sum_{r=1}^{\infty} \frac{A_r \cos (k - m + 2) \frac{r\pi}{k+1} \sin \mu_r \frac{l}{k+1}}{\sin \frac{r\pi}{k+1}}$$

$$= \sum_{r=1}^{\infty} \xi_{m,r}$$

First, consider the wave lengths of these oscillations of type $\xi_{m.r}$. Begin with the fundamental

$$\xi_{m,1} = \frac{A_1 \cos (k - m + 2) \frac{\pi}{k+1} \sin \mu_1 \frac{l}{k+1}}{\sin \frac{\pi}{k+1}}$$

As m increases from 1 to $k + 2$ the angle $(k - m + 2)\pi/k + 1$ diminishes from π to 0. In Fig. 4 the line $L_1 L_1$ represents the length of the loop. L_{k+2} is the middle point of it. Points 1, 2, 3.... $k + 2$ mark the position of the reactance points. At these points measure off abscissæ equal to $\xi_{1,1}\ \xi_{2,1}\ \xi_{3,1}$..... The extremities of these abscissæ will be on the harmonic curve 1. This curve represents the fundamental oscillation of displaced period. Its wave length is 2 l, the same as the wave length of the fundamental oscillation before the introduction of the reactance points.

The next component is

$$\xi_{m,2} = \frac{A_2 \cos (k - m + 2) \frac{2\pi}{k+1} \sin \mu_2 \frac{l}{k+1}}{\sin \frac{2\pi}{k+1}}$$

As m increases from 1 to $k + 2$ the angle $(k - m + 2)\, 2\pi/k + 1$ diminishes from 2π to zero. It will, therefore, have four maxima and four zero points on the loop. Its wave length is l. This component is represented by curve II in Fig. 4.

Take now the last component but one of the first group of free oscillations of displaced period. It is

$$\xi_{m,k} = \frac{A_k \cos\,(k - m + 2)\, \dfrac{k\pi}{k+1} \sin \dfrac{\mu_k\, l}{k+1}}{\sin \dfrac{k\pi}{k+1}}.$$

As m increases from 1 to $k + 2$ the angle $(k - m + 2)\, k\pi/k + 1$ diminishes from $k\pi$ to zero. This component has, therefore, $2k$ maxima and $2k$ zero points on the loop. Its average wave length is $2\,l/k$. The last component of this group is the same as the lowest oscillation of normal period—that is, η_{k+1}.

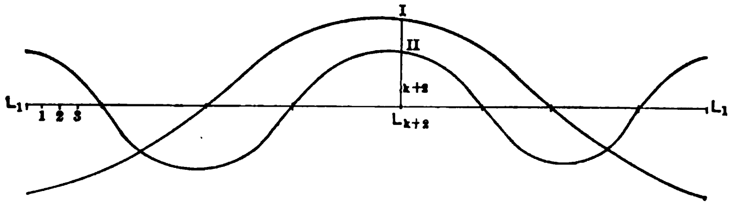


FIG. 4.

The components of the first group have, therefore, the same average wave lengths as the components of the first group of free oscillations on the loop before the introduction of the reactance points.

It can now be easily shown that this is true for the components of all the other groups, and attention should be called here to the fact that the wave lengths of the free oscillations of displaced period can be considerably smaller than the distance between two consecutive reactance points. The introduction of the reactance points changes, therefore, neither the number of free oscillations nor their average wave length. Their periods, however, and their damping constants will be changed, as will be shown presently.

DISPLACEMENT OF PERIODS.

The periods and damping constants of the oscillations of displaced period are determined from the period equation

$$\frac{h_r \sin \dfrac{\mu_r l}{k+1}}{\mu_r} + 2 \cos \frac{\mu_r l}{k+1} = 2 \cos \frac{r\pi}{k+1}.$$

The unknown quantity ν_r contained in h_r and μ_r is, of course, a complex quantity—that is. we can write

$$\nu_r = n_r + ip_r.$$

I am not as yet quite ready to discuss fully the general properties of the roots of the period equation. Besides, such a discussion would go considerably beyond the limits of this paper, the principal object of which is to determine the conditions under which the non-uniform conductor of Fig. 3 is equivalent to a uniform loop. I shall limit myself, therefore, to a brief statement of those properties only of this equation which bear directly upon these conditions.

First, since

$$\cos \frac{r\pi}{k+1} = \cos \frac{[2s(k+1) \pm r]\pi}{k+1}$$

it follows that the periods and the damping constants of the wave lengths

$$\frac{2l}{r}, \frac{2l}{2(k+1) \pm r}, \frac{2l}{4(k+1) \pm r}, \ldots \frac{2l}{2s(k+1) \pm r}, \ldots$$

are determined from one and the same angle $\psi = r\pi / (k+1)$. This relation between these wave lengths is illustrated graphically in Table I. The horizontal top bar marked 1, 2, ...k + 1,.... 2k + 1, 2k + 2, 2k + 3........contains a numerical record of all the possible wave lengths

$$\frac{2l}{1}, \frac{2l}{2}, \ldots \frac{2l}{k+1}, \ldots \frac{2l}{2k+1}, \frac{2l}{2k+2}, \frac{2l}{2k+3} \ldots$$

The first vertical column marked 0, 1, 2, 3,. ... k + 1.....

contains the record of all possible values of r. The meaning of the black dots is now easily explained. Take, for instance, the row of black dots in the horizontal bar 3. These dots are in columns 3, 2 k — 1, 2 k + 5, 4 k + 1, 4 k + 7,..... This means that if in the period equation

$$\frac{h}{\mu}\sin\frac{\mu l}{k+1}+2\cos\frac{\mu l}{k+1}=2\cos\frac{r\pi}{k+1},$$

we put $r = 3$ then the roots of the equation will give us the periods and the damping constants for the wave lengths

$$\frac{2l}{3},\ \frac{2l}{2k-1},\ \frac{2l}{2k+5},\ \ldots\ldots\ldots$$

TABLE I.

λ

r	1	2	3	4		K−1	K	K+1	K+2	K+3	K+4		2K−1	2K	2K+1	2(K+1)	2K+3	2K+4	2K+5		3K	3K+1	3K+2	3K+3	3K+4	3K+5	3K+6		4K+1	4K+2	4K+3
0																●															
1	●														●		●														●
2		●												●				●												●	
3			●										●						●										●		
K−1						●				●												●				●					
K							●		●														●		●						
K+1								●																●							
K+2							●		●														●		●						
K+3						●				●												●				●					

For this reason these may be called the *concomitant wave lengths.* An inspection of this table shows that the concomitant wave lengths are symmetrically arranged with respect to the wave lengths of normal periods

$$\frac{2l}{k+1},\ \frac{2l}{2(k+1)},\ \frac{2l}{4(k+1)},\ \ldots\ \ldots$$

Of a given series of concomitant wave lengths there is one in each of the groups mentioned above. The first one of these groups contains the longest wave lengths; it may be called the *fundamental group.* The wave lengths of this group, together with their concomitant wave lengths, give all the possible wave lengths. If in the period equation r is given successively the values 0, 1, 2, ... k + 1, the roots of the resulting k + 2 equations will give the periods and damping constants not only for the wave lengths of the fundamental group, but also their concomitants—that is, for all the wave lengths. It should be observed that the more nearly cos $r\pi/(k+1)$ approaches the value +1 or —1 the more closely will the concomitant wave-lengths approach the wave lengths of normal period, around which they are symmetrically grouped, and therefore the more closely will their periods approach the period of the central wave length. For instance, the wave lengths

$$\frac{2\,l}{2\,k+1} \text{ and } \frac{2\,l}{2\,k+3},\ \frac{2\,l}{4\,k+3} \text{ and } \frac{2\,l}{4\,k+5} \cdots\cdots\cdots$$

are concomitants of wave lengths $2\,l/1$. Their periods are obtained from the period equation by putting $r = 1$. This makes cos $r\pi/(k+1)$ approach the value + 1, and therefore the periods of wave lengths

$$\frac{2\,l}{2k+1} \text{ and } \frac{2\,l}{2k+3},\ \frac{2\,l}{4k+3} \text{ and } \frac{2\,l}{4\,k+5},\ \cdots\cdots\cdots$$

will approach the periods of the wave lengths

$$\frac{2\,l}{2\,(k+1)},\ \frac{2\,l}{4\,(k+1)},\ \cdots\cdots\cdots$$

which have been calculated above. When, therefore, k is large then the roots of the period equation

$$\frac{h}{\mu}\sin\frac{\mu\,l}{k+1} + 2\cos\frac{\mu\,l}{k+1} = 2\cos\frac{r\,\pi}{k+1},$$

come out in pairs of nearly equal magnitude for all values of r, which are small in comparison to k. This peculiar property of the roots of the period equation suggests a striking resemblance between the oscillations of a periodically loaded conductor and the luminous vibrations of an incandescent gaseous substance, which, in my opinion, deserves serious attention. I expect to discuss this matter more fully at some future occasion.

Equivalence of a Non-Uniform Conductor of the Second Type to its Corresponding Uniform Conductor.

Suppose that we now increase the number of reactance points without increasing the total reactance and resistance introduced into the line. In the expression

$$h = C(\nu^2 \rho + \nu R)$$

put

$$\rho = \frac{l\lambda^1}{k+1}, \quad R = \frac{l R^1}{k+1}$$

Hence,

$$h = \frac{l}{k+1}\, C(\nu^2 \lambda^1 + \nu R^1) = \frac{l}{k+1}\, h^1$$

As the number of reactance points is increased λ^1 and R^1 are to be kept constant; hence, ρ and R must vary inversely as k + 1. When k becomes infinite then all the wave lengths different from zero will be in the first group of Table I between the columns 1 and k + 1. The other columns of this table lose their physical meaning. To show what becomes of the period equation when k approaches the limit ∞ write the period equation in the following form:

$$\frac{\frac{l}{k+1} h_1 \sin \frac{\mu l}{k+1}}{\mu} - 4 \sin^2 \tfrac{1}{2} \frac{l\mu}{k+1} = - 4 \sin^2 \tfrac{1}{2} \frac{r\pi}{k+1}$$

Since wave lengths different from zero are to be considered, finite values only of r need be considered. Hence, when k = ∞ the period equation becomes

$$l^2 (h^1 - \mu^2) = - r^2 \pi^2$$

or

$$C\,[\nu^2 \lambda^1 + \nu R^1 + \nu^2 L + \nu R] = - \frac{r^2 \pi^2}{l^2},$$

or

$$C\,[\nu^2 (\lambda^1 + L) + \nu (R^1 + R)] = - \frac{r^2 \pi^2}{l^2}.$$

This equation is, as it ought to be, the period equation of a uniform conductor of inductance $\lambda^1 + L$, resistance $R^1 + R$, capacity C per unit length. This conductor is the so-called corresponding uniform conductor of the periodically loaded loop.

When k is large but not infinite the same relation will exist approximately, and it is proposed to ascertain now the degree of this approximation.

We have seen that $l\,\mu\,/\,(k+1)$ varies with r as follows:

$$\frac{l\,\mu}{k+1} = s\,\pi, \quad \text{where } r = s\,(k+1),$$

s being any integer from 0 to ∞. Thus, when

$$\frac{r\,\pi}{k+1} \text{ is } 0,\ \pi,\ 2\,\pi,\ 3\,\pi,\ 4\,\pi, \ldots\ldots\ldots\ \ldots$$

$$\frac{\mu\,l}{k+1} \text{ will be } 0,\ \pi,\ 2\,\pi,\ 3\,\pi,\ 4\,\pi \ldots\ldots\ldots$$

Since $\mu\,l/(k+1)$ varies continuously with r it follows that when $r\,\pi\,/\,(k+1)$ is small $\mu\,l\,/\,(k+1)$ will also be small, since both vanish simultaneously. It is well to introduce here the physical meaning of $r\,/\,(k+1)$. Let λ_r be the wave length of the wave for which $\psi = \frac{1}{2}\,r\,\pi\,/(k+1)$, then

$$\lambda_r = \frac{2\,l}{r}, \quad \text{or } r = \frac{2\,l}{\lambda_r}$$

Therefore,

$$\frac{r\,\pi}{k+1} = \frac{2\,\pi}{\lambda_r}\,\frac{l}{k+1} = 2\,\pi\,\frac{l_1}{\lambda_r}.$$

where l_1 is the distance between two consecutive coils. Let $2\,\pi$ be the angular distance of λ_r and θ_r be the angular distance of l_1 corresponding to the period of λ_r, then

$$\frac{l_1}{\lambda_r} = \frac{\theta_r}{2\,\pi},$$

Therefore,

$$\frac{r\,\pi}{k+1} = \theta_r.$$

Since for small values of $r\,\pi\,/\,(\mathrm{k}+1)$ the angle $\mu\,l\,/\,(\mathrm{k}+1)$ is nearly equal to $r\,\pi\,/\,(\mathrm{k}+1)$ it follows that within these limits $\mu\,l\,/\,(\mathrm{k}+1)$ is approximately equal to the angle θ_r. It follows, therefore, that wave lengths for which θ_r is sufficiently small the period equation

$$\frac{l}{k+1}\,\frac{h^1}{\mu}\sin\frac{\mu\,l}{k+1} - 4\sin^2\tfrac{1}{2}\,\frac{l\,\mu}{k+1} = -\,4\sin^2\tfrac{1}{2}\,\frac{r\,\mu}{k+1}$$

can be written

$$\left(\frac{l}{k+1}\right)\,h^1 - \left(\frac{l}{k+1}\right)^2\mu^2 = -\left(\frac{r\,\pi}{k+1}\right)^2,$$

or

$$C\,[\nu_r^2\,(\lambda^1 + L) + \nu_r\,(R^1 + R)] = -\left(\frac{r\,\pi}{k+1}\right)^2,$$

that is, the periodically loaded conductor has approximately the same period, damping constant and, of course, the same wavelength as its corresponding uniform conductor. The degree of approximation is of the same order as the degree of approximation between one-half of the angular distance separating two consecutive coils and the sine of that distance.

It should be observed that if the whole loop is divided into a number of equal parts and the consecutive parts are connected to each other by mutual induction, then the non-uniform conductor thus obtained will act in the same way as the non-uniform conductor of Fig. 3 of this section. Another arrangement, which is equivalent to the two arrangements so far described, is obtained by placing bridges at periodic intervals of the uniform loop, each bridge consisting of a coil of proper resistance and inductance, and the distance between the bridges being adjusted in accordance with the general rule formulated here. The mathematical analysis of these two arrangements does not differ essentially from the one given here, and can be easily worked out.

A rule governing the degree of approximation between a non-uniform conductor and its corresponding uniform conductor has thus been established, and it has been proved that the same rule is applicable to both types of non-uniform conductors, and also to both forced and free oscillations. The principal object of this investigation has, therefore, been accomplished.

Discussion.

The President:—Seven years ago the electrical fraternity was startled with a paper on Ocean Telephony. But seven years have passed and we have not yet telephoned across the ocean. The present paper differs from this other one, which was read by an Englishman, in that, in the first place it makes no such extravagant claims as ocean telephony, and in the second place it verifies by actual experiment, the application of a very interesting theory.. Papers like this, and the preceding one, show what good results can be accomplished by a careful and intelligent application of correct theory. Such papers reflect great credit on the Institute. The paper is now open for discussion.

Mr. Steinmetz:—Mr. President, I have been very much pleased to listen to this highly interesting and extremely important paper, which marks a decided advance in the art of telephony, as I believe. Now, coming first to a comparison with previous propositions for improving the method of telephony over cables, there is an essential difference between the present case and the previous ones. In the latter, if I remember rightly, it was proposed to distribute inductances along the cable, these inductances to be shunted across the cable. The capacity of the cable and the static capacity act as a shunt across the line. If you want to compensate for the effect of capacity by self-induction, or self-induction by capacity, one must be in shunt and the other in series. That is to make up for the electrostatic capacity of the cable. That is the case here. The phase relation and frequency will remain the same throughout the whole line. This was not the case with the previous proposition. The problem of transmitting alternate currents leads to two very distinct phenomena and problems, that of transmitting very large powers at very low frequency relatively, and high voltages, with the so-called electric power appliances, and then the transmitting of very small powers at very high frequencies at very low voltage. That is telephony. The theoretical aspect of the problem is the same, but they have to be conducted entirely different. The solution of the problem in the one case is entirely inapplicable to the other case. Theory has to go ahead of investigation, except by mere luck in an individual case you find a solution, and in the next case you reach the same solution and it is entirely wrong. We have found means to compensate for the effect of self-induction by synchronous apparatus. Self-induction is not an objection any more; it is rather an advantage. We have a similar problem in the system of telephony, only there it is not the self-induction which is very small in the ordinary telephone, at the frequencies and voltages in current use, but it is the capacity which is the dangerous objection. The attempt to use the solution which is satisfactory in power transmission would not be fair because the two conditions are entirely different. The shunt across is entirely unsatisfactory and makes the problem worse, it spoils what little transmission of speech we can get. In America we have investigated the transmission at very high voltages and at relatively low frequencies. There is a certain value in self-induction but it is not at all essential in most cases to have exactly this value. You can get half as much and still the transmission is very much improved over what it would be without the self-induction. The more you put the self-induction in the better it becomes.

Referring to the second part of the paper, the mathematical side, I have not read it yet, so I cannot say anything about it. If any further suggestions occur to me I shall communicate them in writing.

Dr. Crehore:—Mr. President, I would like to make one inquiry. It occurs to me that in looking up the proportions to form a distortionless circuit the value of i or the reduction required is invariable; that if you were to send a sine wave into the cable the energy that you get through is necessarily very much reduced from what it would be without the induction. I would like to ask Dr. Pupin for a comparison of the amount of energy that he gets through this 250-mile cable by sending a constant voltage, say of 30 to 50 volts. I would like to form a comparison between the amount you get through the cable when you have those coils in, and when you do not, because it seems to me very important as to the distance that you will be able to cover.

Dr. Pupin:—The ratio is 1 to 10,000.

Dr. Crehore:—The ratio between the energy you would receive and otherwise?

Dr. Pupin:—Yes. By making a certain arrangement you can get it constant within practical limits. In this particular case the ratio of the current put in at one end and the current received at the other end is 50 to 1. Two per cent. of the current that is put in at one end is received at the other end when you put the coils in, and of course that is all that is needed for telephony over that length. If you did not have the coils in, instead of 1 to 50 you would have 1 to 125,000.

Dr. Crehore:—You mean you would get a larger amount with the coils in?

Dr. Pupin:—Yes; very much larger. I say 1 to 125,000. I could not get any current through at the other end at all that I could detect with the telephone. I believe you do not get anything through to speak of.

Dr. Crehore:—Sending a simple sine wave?

Dr. Pupin:—Sending a simple sine wave by means of the alternator; that is, using about 15 volts at one end. This calculation refers to about 625 periods per second.

Prof. Franklin:—What is the condition of this circuit with regard to the distortion?

DR. PUPIN:—The attenuation constant is the same for all frequencies, and therefore the circuit is distortionless. If there was any difference at all in the relation between the attenuation and the frequency I did not notice it.

PROF. FRANKLIN:—You did not take precaution beforehand to satisfy the conditions.

DR. PUPIN:—Yes. I did not want any distortion. I could have detected it experimentally up to about two per cent. on an average. Up to that limit there is no dependence between the frequency and the attenuation. If it is anything less than two per cent. it does no harm.

MR. STEINMETZ:—Since they have been speaking of distortion, I desire to sound a note of warning. As I said before, the solution in telephony is entirely different from that in power transmission at low frequency. That does not mean that the proper method of alternating current transmission is to put in as much capacity as to make it distortionless. Take a telephone cable and impress it with the ordinary electro-motive force; then you will require a very large impressed power to get the same current out of the cable without inductance.

DR. PUPIN:—I would like to correct a statement which our worthy president has made. It is not an error on his part, but rather a misunderstanding. He said I did not make a claim to telephony on an ocean cable. I do decidedly make that claim.

THE PRESIDENT:—You did not make the claim in the paper.

DR. PUPIN:—I did not make it in this paper, because I reserved it for another paper which I expect to bring very soon before this INSTITUTE, in which I shall discuss the cable problem in all its details. But I do now state decidedly that I am convinced that telephoning over a cable of reasonable length, say 1,000 miles to start with, is quite possible and nothing at all extraordinary.

PROF. FRANKLIN:—I would like to ask Dr. Pupin a question, and that is, why not apply this method which you have been working upon to simply increasing the possible speed of telegraphy? It applies to that equally with telephony. Why telephone across? Why not apply it to increasing the speed of signaling.

DR. PUPIN:—That goes without saying. It will help telegraphy as well as telephony. Of course it would increase the speed of telegraphy. You can take a distortionless loaded conductor like the one described in this paper and transmit five or ten different messages over the same wire. That would be even more important than telephony, but I don't know that it would be as interesting from a scientific point of view.

THE PRESIDENT:—When I said that Dr. Pupin did not make any claim to ocean telephony I meant to compliment him; I meant to say that he claimed no more than what he had really accomplished, and that it was in this that his paper differed very radically from the other one to which I referred. Concerning ocean telegraphy, or at least trans-Atlantic telegraphy, it should not be forgotten that in telephoning east and west there is another factor which enters, and that is that the business days in London and New York, for instance, differ by five hours and do not overlap for a sufficient length of time to make it pay to have a cable for telephoning across the Atlantic unless such a cable could also be used at other times for telegraphing. To simply have a cable for telephony I am afraid would hardly pay, because the time of utilization would only be about two or three hours out of the 24. This does not apply to telephoning north and south.

Dr. Crehore:—I would like to inquire whether I am anticipating too much to ask Dr. Pupin whether he is prepared to show a form of cable which he could put such coils into or indicate how a cable is to be constructed for submarine work, or whether he chooses to reserve that for the paper which he intends to present in the future?

Dr. Pupin:—No; it is no secret. I did not talk about it, because I have not yet sufficient experimental data on that particular form of cable, but it is a cable of the same kind as the one discussed in this paper. There is only this distinction, and it is only a distinction in degree and not in principle at all. I said a little while ago that on a land line of 2,000 miles, say between here and New Orleans, if you wanted to introduce coils at a distance of two miles it would be sufficient, but if you have a cable where the capacity is large, then the coils have to be placed at much smaller distances apart. I made a calculation for a particular form of cable, say three-tenths of a microfarad per mile and four ohms resistance per mile, and in order to give the cable a sufficiently small attenuation constant for 750 periods I introduced inductances so as to give three-tenths of a henry per mile. I made the reactance coils smaller. I wound the core two inches and a half external and one inch internal diameter and six inches long with very fine iron wire. That is where the whole trick comes in—to have fine wire. It is necessary to have iron wire two mils in diameter. I am informed by some manufacturers of iron wire in Worcester, Massachusetts, that they would fill such an order if I wanted it at once. This is very fine Swedish iron wire. They can draw it very easily down to two mils diameter. You wind two coils in inductive relation to each other, each 40 turns, copper wire, and then you place them eight coils per mile. That is at a distance of between 600 and 700 feet apart. Coils like that can go right into the sheathing of the cable. It is all a question of Foucault current losses in the iron. The Foucault current losses can be reduced to a very small amount. I calculate that 25 coils like that, with a frequency of 750 periods, would be equivalent to adding one ohm to the line. So that form of cable is a practicable form. Instead of having them 700 or 800 feet you can make them a little more frequent.

Mr. Hommel:—It appears to me that the main point just at present is to see whether it is practicable to telephone for any such distance through the capacity of an ocean cable and resistance, and if it is, the working out would be a matter of detail. Even if the coils could not be made in just this manner, it appears to me it would not matter. If they were a little larger there could be some mechanical arrangement devised so as to take the strain off the coils, and while this arrangement as well as the other would undoubtedly make the cost of manufacturing the cable higher, probably the income from being able to telephone across would warrant the expense; and it appears to me the main point would be to find out whether it is practicable to telephone any great distance over an ocean cable by means of self-induction added at intervals as shown.

DR. PUPIN:—But one more remark. Nobody cares so much for ocean telephony anyhow. It is not so very important. It is very interesting from a purely scientific point of view, but whether it is of so very great commercial importance I am not prepared to say. I am rather inclined to think the other way. I think telephony on land lines is the point. We have reached the limit of telephony over land lines. We cannot telephone over 1,000 or 1,200 miles with any sort of satisfaction. The telephone men themselves tell me that it is a somewhat unsatisfactory business to telephone between St. Louis and New York. You have got to repeat your sentences very often. The lines are too expensive. The circuit between New York and Chicago costs for copper alone $250,000. Now, supposing you wanted to extend the limit of telephony and wanted to go to San Francisco or to Kansas City, unless you spend four or five times as much per mile on the circuit you cannot telephone at all. Then you have other considerations—the weight of the wire, etc.—and according to the views of the telephone men themselves it is impracticable to carry on the telephone business over a distance longer than 1,200 miles. By spending a few dollars for these coils, at proper distances apart, I would undertake to build a line between New York and New Orleans, although I am not a practical engineer and I do not care so very much for commercial work, but just for the sake of showing what could be done I would undertake to build a line between New York and New Orleans that would be four ohms per mile; that is twice the resistance per mile of the standard wire between New York and Chicago. I think that this is the really important problem—the problem of extending the limit of telephony over land lines.

THE PRESIDENT:—If there is no further discussion we will go on with the next paper. The title of the next paper and the last one is "Notes on Synchronous Converters," by Prof. R. B. Owens, of Montreal.

[This paper will be printed subsequently.—EDITOR.]

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

PARIS, FRANCE, August 16th, 1900.

The Seventeenth General Meeting of the INSTITUTE, adjourned from Philadelphia May 18th, 1900, was continued as a joint meeting with the Institution of Electrical Engineers in the United States Pavilion at the Paris Exposition August 16th, 1900, under the joint chairmanship of Presidents John Perry of London, and Carl Hering of Philadelphia. The meeting was called to order at 9:30 A. M., by President Hering, who spoke as follows:

PRESIDENT HERING:—It gives me great pleasure to open this meeting, the first one held jointly by the Institution of Electrical Engineers and the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Such international meetings between societies whose aims are alike, but whose surroundings are different, cannot fail to be of interest and benefit to all who take part, and to draw closer together the different nations which participate, thus strengthening the ties which bind together the electrical engineers of different countries.

The promising success of the present session gives us reason to hope that it will soon be followed by other similar international meetings of electrical engineers.

In behalf of the members of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, I wish to thank you, Mr. President and Members of the Institution of Electrical Engineers, for the great pleasure you have given us by joining us in this international gathering. It was quite a venture for us to hold a meeting so far away from home; in fact, when I first suggested it some years ago, the proposition met with some ridicule by members of our board of managers. When we found, however, that our older and larger sister society in England joined us so heartily in our proposition, the success of our venture was at once assured. I feel sure that those of our members who are present, and many who are not, hope that this, our first joint meeting, will be the beginning of a series of similar meetings of our sister societies, and that the next one will be in the home of our INSTITUTE.

[Mr. Hering then made a few remarks in French and in German, welcoming the guests from other foreign countries, and expressing the hope that the electrical societies of the leading countries will join in holding similar meetings, the next one of which he hoped would be in the United States].

In accordance with the arrangements of our Joint Committee, there will be two presiding officers. Prof. Perry, as the senior officer, will conduct the affairs ot the meeting, and will now address you.

PRESIDENT PERRY, F.R.S. :—After a very few words from me we shall commence the discussion. I can only say to the Americans who are now our hosts in this building that their visit to England gave us very great happiness indeed for four days. I think that every Englishman who joined in the parties feels that it did really give us more pleasure than it was possible for our guests to experience.

There are no minutes to be read at the beginning of this meeting, because there have been no such meetings in the past, but minutes are being prepared of this discussion, and let us hope that they will be read on a future occasion. In the name of the two Institutions of Electrical Engineers, we welcome you, ladies and gentlemen, to this meeting.

I will now ask M. Mascart to say a few words.

PROF. E. MASCART :—I must first very cordially thank the Institution of Electrical Engineers for the exceptional honor bestowed, in naming me Vice-President; I have been greatly touched by this particular mark of esteem, and, I may add, of affection, on the part of the members of this society.

It was just now suggested that it would be very useful to have more frequent reunions similar to this; that is to say, meetings, including members of the electrical societies of the most important nations. You have begun by setting the example, and we thank you for having gathered together in Paris, the members of the two great institutions of America and England. We will agree to go to the United States; I assure you it would be a very great pleasure for me to do so, for I have very pleasant recollections of a journey there several years ago, but I am getting to be one of those who do not travel much. I hope nevertheless that the members of the French Society of Electricians, who are already considering that question, will respond to your invitation, and that very soon you will be able to hold in America, at Philadelphia, for example, a reunion of the societies of electricians of America, England, France and Germany, without counting other countries.

But if I cannot be one of you on that occasion, I shall accompany you, nevertheless, with my sincerest wishes for the success of your reunion.

Now, in the name of French electricians, in the name of the Society of Electricians, I thank you again very cordially, for choosing the city of Paris as the place to hold the sitting of your associated societies. I particularly thank our two honorable Presidents who took the fruitful initiative in this extra-territorial reunion.

President J. Perry:—I will ask Mr. Ferranti to open the discussion.

A Topical Discussion at the Joint Meeting of the American Institute of Electrical Engineers and the Institution of Electrical Engineers, Paris, August 16th, 1900, Presidents Hering and Perry presiding.

ON THE RELATIVE ADVANTAGES OF ALTERNATING AND CONTINUOUS CURRENT FOR A GENERAL SUPPLY OF ELECTRICITY, ESPECIALLY WITH REGARD TO INTERFERENCE WITH OTHER INTERESTS.

[A Topical Discussion.]

Mr. S. Z. de Ferranti:—I am indeed greatly honored by being allowed to open the discussion at this most fortunate meeting. I say most fortunate, because you will all agree with me that nothing could be better than that the American and English associations of Electrical Engineers should have a joint meeting. There is only one thing in my mind which is perhaps better, and that is that we should be holding this meeting in Paris, and thus show what a great tie really unites us all, and how much more friendly our feelings really are than is often supposed. The subject for this discussion was left for the English Institution to select, and I can assure you, gentlemen, that it was a matter of no little difficulty to decide upon what we should discuss. The subject which has been chosen you may at first think is simply a revival of the old contention between alternating and continuous current. I hope, however, that it is no such thing. Matters have greatly changed since the early days when the advocates of each of the two systems were, I may almost say, bitter enemies, and when they thought that everything that was done by the other side was wrongly done. We have all found that that is not so, and that there are great merits in the particular uses of both systems. But, as I have said, things have changed, and they have not changed yet as much as they are going to change in the future. The question that we have to deal with must be considered in the light of what electricity will be ten, fifteen, or twenty years hence. You have seen how the industry has grown; you know, by being members of the electrical profession, how much it has done up to now. I think few of us, although it is our life's work, realize what electricity is going to grow to, and how important and universal a part it is going to play. It is, however, in this light that we must consider what are the best lines to be worked upon. It is no longer the small isolated systems which could be worked on one plan or another according to convenience; that we have to deal with, but it is the question of transmitting and using big powers all over large areas. Now, with regard to the advisability or desirability of one system, the continuous as against the alternating current: many of you know that I have consistently worked with alternating currents, and you will therefore appreciate that my knowledge of the other subject is not what it should be as compared with that of those who have worked more exclusively in that direction. I, however, desire to dissociate what I have done from what I am going to say, and rather than give so much my own opinion, I shall suggest a few points to you bearing upon what the general opinion is on this subject, as I consider it most important.

Looked at from the new point of view, this is what presents itself. Which will be the possible system in the future? I say "possible" because many of us have had very serious experiences of the electrolytic effects which are produced to such a large extent by the continuous current. What I am wondering is this: If this system is developed and extended to a very large extent, will it be possible satisfactorily to preserve any metal work in the earth at all? We have not only got to deal with the lead coverings of electric cables, but we have also any amount of structural ironwork—water mains, railway rails, gas mains, water pipes, and all sorts of things—the quantity of which is increasing every day in our streets all over the country. The amount of property invested underground in one or other of these forms is reaching a very great figure; and it becomes a serious question for us, not so much in the light of to-day, but in the light of the future, when immense developments will have taken place, to know on what lines we should go, and how best to protect this immense property, which may be injured by the otherwise beneficial work which we are doing. Of course alternating currents are not quite free from the liability to produce some harm, but what little harm they can do is not of commercial importance. Therefore I consider it will want our most careful thought and work and investigation to find out really how we can diminish these electrolytic troubles, due to continuous currents, or whether it will not be necessary to substitute alternating current, which produces but slight detrimental effects, and see how to overcome what disadvantages are now left to it. I hope that a great many of you gentlemen present will give us valuable information on this subject, and, after you have left this meeting, having heard the discussions which have taken place, that during the next few years you will give the matter your careful consideration, and then contribute your views through the electrical press, or by another such meeting as this, to the electrical profession at large.

Again, gentlemen, I must thank you for having been allowed to open this discussion. I hope it will be a full discussion, and that what I have said may stimulate discussion and lead to careful consideration of the subject which will prove beneficial to the electrical industry in the years to come.

MR. BION J. ARNOLD:—I wish to express my appreciation of the honor conferred upon me by being permitted, in this discussion, to follow so distinguished a worker in the electrical field as Mr. Ferranti. I did not know about my colleagues' intentions of calling on me this morning until late last evening, otherwise I would have taken time to prepare my remarks. We have all heard that the man who dares to assert that "electricity is in its infancy" is liable to annihilation on the spot; but after Mr. Ferranti's remarks I fancy we may be considered, for the moment at least, to be on the threshold after all.

I think it may bring out the discussion of this subject between the different countries, here represented, more thoroughly if I outline briefly the practice in the country which I come from, viz., the United States of America. For lighting work we started in our large cities with the direct current system as advocated by Mr. Edison. By the way, I once saw a letter from Mr. Edison, written some ten years ago, in response to an inquiry addressed to him asking his views on the relative advantages and disadvantages of the alternating and direct current. His letter intimated that he thought the alternating current was of Satanic origin, that it was a delusion and a snare, and that no good could come out of it. Mr. Ferranti has proven that the contrary is the case, and judging from his remarks and the work of many others it seems as though the ideas of his Satanic Majesty may yet prevail.

Returning to our subject, we started in our large cities with the direct current system and in our smaller cities with the alternating system. To-day the direct current seems to have not only held its own in our large cities, but, in addition, is replacing the alternating system in some cases, although the alternating system holds its place for smaller cities covering widely distributed districts and for transmission to the outlying districts of our larger cities. In the city of Providence, Rhode Island, one of the first and leading cities in the electric lighting industry, the alternating apparatus originally installed has been entirely thrown out, in the underground districts, and replaced with a direct current system of supply, delivering energy on a three-wire 480–240 volt system. The same thing is taking place in the city of St. Louis, Mo., although at that point they have not abandoned the use of the alternating apparatus, but a competing company has installed a direct current system on the 480–240 volt three-wire system, which company has largely taken the business of the alternating company within the district it reaches, and the net earnings and operation of the direct current company have been very satisfactory. I mention these two important installations to emphasize my statement that the direct current is holding its own in our larger cities. I believe the alternating current will hold its prestige in our smaller cities and in the outlying districts of our larger cities.

In answer to Mr. Ferranti's advocation of the alternating current for lighting work in large cities, I will say that there is no means, so far as I know, for equalizing the load upon the power station when the alternating current is used, thus losing the advantages gained in direct current work when using storage batteries. The installation in the latter case would require less investment than would be necessary if the alternating current were used, assuming a reasonable area over which the energy is to be distributed.

Coming now to railroad work, we started with a 500-volt direct current system, and gradually increased to 600 and 700 volts, and are now utilizing the latter on the sections of the roads contiguous to the power houses, and driving our more distant sections with three-phase 25 or 30 cycle alternating current. I believe this will be modified, and that the alternating current will ultimately predominate in railway work. I believe that we shall soon eliminate entirely the sub-station, the rotary converter, and possibly the static transformers at the power house. We shall at least eliminate the sub-stations. Mr. Ferranti is no doubt working on this theory, and so also are others, in the respective countries here represented, including some from the United States. Some of us feel that there is a fair hope for success. It may, of course, be slow in coming, but that it will come I have no doubt. There are two main difficulties at present in the way of a complete and successful alternating current railroad system. The first is a lack of a practical method of starting and controlling the speed of an alternating motor without excessive consumption of energy. The second is the one pointed out by me when referring to lighting work, viz., the lack of a load equalizer corresponding to a battery in direct current work. Some of us are hoping for and endeavoring to develop a system by means of which we will utilize or have the advantages of an equalizing reservoir as it were, thereby taking the place of the storage battery in direct current railway work. I believe this is coming, and if it is successful we shall have an ideal system for long-distance railway work, utilizing all the advantages of the alternating current for transmission, and the advantages of the equalized load factor for economy, and we shall not have the disadvantages of the sub-station and its corresponding maintenance and labor expense.

I do not know that I can add anything more to the discussion, but if I have succeeded in pointing out, in a general way, the lines upon which the engineers of our country, and possibly of others, are working in the lighting and railway fields, it is all

I can reasonably hope to do in the time allotted to me. If any further information is desired regarding the details of the work to which I have alluded, I will, if the questions are asked, give such information as I can consistently at the present time.

Sir William Preece:—I feel somewhat in the same position as the blank leaf between the Old and the New Testament. I am here as a past President of the British Institution of Electrical Engineers, but I am also an Honorary Member of the Institute of Electrical Engineers of America. I therefore speak in the blank-page capacity. I also hold the position of never having compromised myself by associating myself either with the direct current or with the alternating current system. I have used both when I thought either was right. I believe there are circumstances in which the one is essential, and under different circumstances, where the other properly comes in.

Now, we want to consider the subject before us from different points of view. We have to consider generation, we have to consider the distribution of our currents, and we have to consider the transmission of these currents to great distances. In the first place, we have to deal with the generation of our currents, and there we start exactly from the same point, for we must remember than an ordinary dynamo is nothing more nor less than a simple alternator. So we start from the same basis.

Mr. Ferranti commenced his remarks by referring to some of the disturbances. He dealt with the electrolytic effect upon pipes and metallic coatings. There is another serious disturbance that has caused many of us anxious moments, and that is the disturbance produced by alternating currents upon telephones. I have always said the telephone is perfectly competent to take care of itself. The alternating current engineer need not worry himself about telephones. The telephone is never complete until it has worked on metallic circuit, and when that metallic circuit is tested and properly maintained, no alternating currents, whatever their frequency, whatever their strength may be, can possibly affect telephones. There is another serious difficulty that we have met with in our practice, and that is disturbances to railway signals. Although under ordinary normal conditions alternating currents cannot affect the railway signals, there may be sudden rushes to earth due to those strange effects that were once called, and rightly called, Ferranti effects, certain sudden effects of momentum in alternating circuits which raise the voltage so that the insulation is pierced by great surgings of current. Such things have produced, and will produce, false signals on our block system unless some step is taken to prevent them.

The rest of the disturbances are comparatively trifling in their frequency; but they have been serious in their consequences. There are the fires that have been caused by some of these surging effects to which I have alluded. Now, in determining the necessity for the use of either system, we have not only to consider what I have said, but we have to consider the use to which it is placed. There is first electric lighting, next motive power, thirdly traction, and fourthly the transmission of power to a distance. I do not think there is a single man in this room who would not agree that the only practical and the only possible way to transmit energy to a great distance is now the triphase alternating current system. No high pressure continuous machine has yet been constructed which could possibly do what is being done between Niagara and Buffalo, and in California, and in Switzerland. There can be no question that for transmission the alternating currents must be considered pre-eminent.

As regards motive power, we come to quite another question. There is no doubt at the present moment that the triphase motor is as good as, if not better than, the continuous current motor under some circumstances. Mr. Arnold referred to the fact that in his country the continuous current was holding its own and displacing the alternating current. Here in France—I forget where at the present moment—there is an illustration, where continuous current machines have been removed, and replaced by triphase, in consequence of the superiority of the triphase over the alternating current. So we have this curious see-saw going on; at this side of the water the triphase supplanting the continuous current, on the other side the continuous current supplanting the triphase. The moral is, that each in its own sphere is good, and as both are used, there can be no serious defects in either the one or the other.

One of the most important questions which has not been raised, and which I should wish to raise, is that relating to the necessity of standardizing the frequency. I cannot perhaps remember all the cases, but we commence with Niagara. There the frequency is 25. There is another large installation where it is 45. In many places in England—and Mr. Ferranti himself has started one in the south of London—the frequency is 50. At Deptford, in an installation which he originated, the number is now 67. We come to the city of London, where I think it is 97 or probably 100. In our first alternating current systems in London we started at Sardinia street with 130. Now we find that the frequency is varying in different parts of the world from 25 to 130, and that shows that there is something wrong somewhere. I believe I am right in saying that the American engineers would have the standard for motive power 25, for ordinary distribution 50, and for house distribution, where each house has its separate transformers, 100. I think that is so, but I have no notes by me to refer to. Anyway, I want to point out that if this joint meeting can possibly do any good it will first allay the impressions that there is any difference among engineers as to the relative superiority of alternating and direct current systems; and secondly that now at this joint meeting we might determine a standard frequency that shall apply to various cases.

I have only one more point to make. That is to call attention to one line of progress along which we are working in England. I refer to the distribution of these triphase currents at high pressures to great distances by means of underground cables. Nearly all the experience in America is with overhead wires. The longest underground system which I know is the one established by Mr. Ferranti between Deptford and Trafalgar Square. This is nearly eight miles long. But underground mains to conduct high pressure triphase currents will be laid to a very large extent, and those engineers who will have the designing and manipulation of these must find out and learn all they can of the effects of capacity, for in all I have read and all I have seen that capacity is practically ignored. Everybody considers induction, which is small in its effects compared with capacity. I anticipate, when we get long lines of twenty or thirty miles transmitting triphase currents at 10,000 volts, great difficulty will be experienced in effects due to capacity.

DR. A. E. KENNELLY:—The occasion which presents itself to-day for the discussion of this subject is, as we have just heard from Sir William Preece, a most fortunate one, namely, for the expression of opinion as to the best frequency which can be adopted for alternating current systems as well as for the cure or dispersal of some of the mists which still hang over the precincts of the fields of alternating current and direct current supply. I think we are generally agreed, not only in America, but also, I think, here and in Europe as a whole, that where you have a densely crowded area to be lit by incandescent lights or arc lights you cannot do better than supply that area with direct current at the pressure at which it is to be operated; and if the area is narrow and constricted, you need not exceed the pressure of a single incandescent lamp, or say about 100 volts. But as the area extends, the quantity of copper you put down becomes so large an item of the capitalization, that you must employ a greater pressure, say 240 or 250 volts, over a distance up to half a mile or a mile. When you come to a greater radius of transmission in your dense area you must employ 500 volts, and finally there arises a limit beyond which it becomes uncommercial to supply the direct current for the direct application, and you must introduce a higher pressure. To introduce this higher pressure you must resort to alternating currents, and so in many of the large cities of America you will find that the heart of the city is supplied by a direct current system on the three wire plan, and then the outlying regions of that same system are supplied through the medium of alternating currents at higher pressures. The pressure increases as the distance of transmission increases. We are all agreed that when the distance of transmission is considerable you must employ the alternating current. On that ground we all stand. Thus when you have to supply electric traction systems at a distance, you inevitably employ the alternating current, and then you resort at the distant end, at least in America, to the direct current supply through the medium of converters. The connection together of those two systems is accomplished with difficulty as well as at considerable expense. There is a set of transformers to reduce the pressure, and then there is rotating machinery required to supply the direct current. This condition of affairs is so anomalous and inconsistent with the otherwise great simplicity of electric current supply, that it is difficult to understand how so remarkable a combination arose. I think it may be claimed to be due to the fact that the electric motor for tramways came into existence gradually and developed as part of a direct current system, and that up to the present time the standard traction systems of America have been all direct current systems. The difficulty of supplying all the apparatus needed upon an alternating current basis, even supposing there were no objections and difficulties to be met with in the alternating current motor, have constituted reasons sufficient to account for the anomalous condition of affairs. If, however, in the future the difficulties which remain in the way of introducing induction motor street-cars can be cleared away, we may expect, as I think Mr. Arnold intimated, that this condition will be eliminated, and we shall have nothing more than a plain alternating current system from beginning to end. The only considerable disadvantage would lie in the difficulty in maintaining a steady distribution of pressure. The difficulty which is encountered in the matter of the distribution of direct currents on electric railroad systems supplied from a distance is, as we know, the electrolytic difficulty. There has been much trouble in America on this account. Many pipes have been destroyed and others have been much damaged by this means. But that difficulty is giving way to careful and deliberate engineering, and it is a much less serious difficulty at the present time than in the past, because engineers know better now what to do. The damage has occurred not so much to large mains as to service pipes crossing the streets, and also to telephone cables where the metallic sheathing is continuous. By careful attention to these conditions, by studying the outlines of the system carefully, this electrolytic difficulty has been, and can be in the future, largely eliminated in maintaining a difference of potential between pipes and tracks not exceeding one volt within the danger area, by putting down a sufficient amount of ground-return copper, and by carefully bonding the tracks. This danger from the electrolytic action resulting in corrosion can be largely eliminated, and we may expect by engineering skill that this trouble will be almost entirely overcome.

One disadvantage, however, which has not been pointed out by preceding speakers in the direction of alternating current traction consists, I think, in the increased hazard from shock and increased danger to life and person. An accidental shock from 500 volts of direct current is not, as a rule, a serious thing. There are cases on record, I believe, where it has proved fatal, but they are certainly very rare, and the number of shocks which are accidentally encountered from day to day over a large number of traction systems is considerable. If, on the other hand, you employ 500 volts of alternating current and get an accidental shock from that, the shock may be much more severe, because it would seem from recent experimental researches that the danger from shock is the danger of disorganizing the action of the heart. The danger in a shock from the direct current is in the first impulse, and may be recovered from; whereas, with the alternating current you get a succession of shocks which may be sufficient to disorganize the heart beyond all chance of restoration.

There are, of course, other outstanding difficulties with alternating current transmissions on railroads, but they are all seemingly of minor consequence. There is, for instance, the disturbance affecting the magnetic needle in general, and those of a magnetic observatory in particular. But it seems to me that the worst that can happen in that case is the banishment of the magnetic observatory from the vicinity of civilized communities to the more desert regions of the earth. While that may be a misfortune and an expense in particular cases, yet the aggregate advantage to the entire community of giving a traction system on the one hand, and removing an observatory on the other, does not appear to be worthy of comparison.

Professor W. E. Ayrton:—The special point to be decided at this discussion, as Mr. Ferranti brought out, is the relative advantage of the alternating and continuous current, especially with regard to interference with other interests. Interference is the main question we have before us in accordance with the title. There is no question whatever that we have had in various countries a very large amount of interference. and therefore I need not go into the details. Electrolytic interference Dr. Kennelly has referred to, as well as others, also telephone interference. A very serious kind of interference has grown up within the last two or three years, namely, interference with submarine cables. A very serious case happened in the Cape of Good Hope, where a large amount of damage was done, and there was considerable stoppage of messages coming by the Western cable to Europe. There has been interference with the magnetic observatories that Dr. Kennelly mentioned at the end of his remarks. There is no question about these interferences, but there is the question how are we to deal with them? Should you endeavor to destroy the attack, or should you allow the attack to remain and endeavor to improve the defence? Those are two totally different methods of dealing with the subject. In other words, should you endeavor to construct each undertaking in a way that it will not cause any interference with anybody else, or will you start with assuming that there is war? Are we to assume that the other side are sure to attack us, and that they will not mind our losses and griefs, and all that we can do is to try to defend ourselves? To a certain extent both practices, both plans, have been followed, in Great Britain, at any rate. The Board of Trade regulations state that there shall not be more than seven volts difference of potential between any two points of the rails if the rails of the tramway are used as a return. That is an indication of an endeavor to prevent the enemy attacking us too much, allowing them to fire at us but not with expanding bullets, so to say. The regulation does not say how long the line may be with such a restriction, whether it is to be a long one or a short one. Still the seven-volt rule applies. Now, it has been shown conclusively that the seven-volt rule does not give sufficient protection. It certainly does not give sufficient protection in the case of a submarine cable which lands anywhere near the place where the tramway runs. It does not give sufficient protection in many cases as regards electrolysis, and obviously it would not give sufficient protection in any magnetic observatory which might be located in the neighborhood of the tramway. In the case of telephones it is possible to obtain a very good defence, and to make the telephone people more or less independent of attack. It was indeed the ease with which that defence can be constructed that led the Joint Committee of the House of Commons and the House of Lords, before whom the matter was brought a few years ago, not to interpose restrictions in the construction of tramways, because the conclusion they came to from the evidence they heard was that a telephone system in Great Britain was so shockingly bad in consequence of the use of the earth as a return—there was in fact so much interference of one with line with another—that even if there were no electric tramways at all, and no distribution of electrical energy on a large scale, it would be necessary for the telephone companies to resort to modifications. They would have to do that apart from electrical distribution, and therefore it was not necessary to restrict electrical distribution because telephones had to adopt their own defence. But regarding the water pipes and gas pipes that does not apply at all. They cannot use anything in the nature of an insulated "return" which will prevent electrolysis.

Now I come to a very important point which has not been suggested by any of the speakers so far—though perhaps I am wrong in saying it was not suggested, as it was implied by Mr. Ferranti—viz., that it would be very different if direct currents were used instead of alternating. But any doubt of the truth of that assertion has not been suggested by any of the speakers. If we were to adopt universally a general system of alternating currents, should we be free from electrolysis? This is a point which has been interesting me for some time past, and I was making some observations on that subject this year in Geneva, where they have suffered a great deal from damage in the pipes. The matter was referred to me to investigate, and I will only remark that it is not at all clear that if only alternating currents were employed the pipes would be free from electrolysis. Some years ago I carried out experiments and showed an interesting one to certain people in my laboratory. I took an ordinary sulphuric acid voltameter, the Hoffman voltameter, with two tubes and a platinum electrode in each tube. The hydrogen was evolved in one tube and the oxygen along the other. We sent an alternating current through, and the same thing occurred as with a direct current, namely, the hydrogen came off in one tube twice as fast as the oxygen in the other. It is clear that we cannot assume that there will be no electrolysis because an alternating current is employed, and I find on this table a sample, of which I did not know previously, which has been sent by Mr. Trotter, of the Board of Trade, illustrating that very thing. The label says: "One of a pair lead pipes buried in a box of earth corroded by one ampere alternating current passing from pipe to pipe for six weeks." That is the result. That is not unlike the corroding seen in Geneva during my investigations. Mr. Trotter mentions in his letter that the specimen was corroded by an alternating current coming from Deptford. That does not mean that the Deptford current is worse than any other. He states that the current came from Deptford to show that it was not any fancy laboratory current. I admit that mine was a laboratory current, but it was produced at any rate by a Ferranti dynamo. The letter proceeds "to show it was no fancy laboratory current—I add it with regret, because Mr. Ferranti will argue, I suppose, that less damage is done by alternating than by continuous current. There are no more particulars to give except that the pipes are six inches apart and the sides where the currents passed each other are more corroded than the other parts."

It is clear, then, that alternating current will not give us protection with certainty, and it is clear also that it is a very important question to examine under what circumstances alternating currents do produce electrolysis, and under what circumstances they do not. That is a subject which has attracted a good deal of attention subsequently to my publishing the little experiment I told you about in connection with the voltameter, and I shall be very glad to hear from the meeting the results of any experiments which will enable us to settle what should be done with a lead pipe so as to make it, if possible, immune to action by an alternating electric current. For it is not possible to do that if such action occurs. If I polarize my platinum plates by means of a direct current first, then decomposition by means of alternating current takes places with perfect ease. I do not mean to say that the same amount of gas came off for a given number of coulombs, which would have come off with the same number of coulombs of direct current, but I mean when the observer saw the voltameter without looking at the ammeter at all, he saw no difference whatever between the hydrogen and the oxygen coming off with the alternating current as compared with that from the two separate tubes with the direct current.

Speaking now about the defence, about arranging our pipes (water and gas), and the submarine cables, so as to prevent the attack hurting us. In spite of what Dr. Kennelly said, I think more might be done to avoid the attack, and I am happy to say the London Tramway Companies have not looked at the matter at all from the drastic point of view that Dr. Kennelly has just suggested. The London Tramway Companies have *not* said: "We are coming. You have magnetic observatories near London. If we destroy them we are very sorry, and you had better go somewhere else." They have not taken that line at all. The line they have taken is: "Will you try and find out for us what we must do, the least we must do, to ensure you immunity from disturbance?" The result, as you know, has been that a Joint Committee was appointed by the Board of Trade to carry out experiments, and find out what was the magnetic disturbance produced by existing electric railways and tramways in Great Britain, when those tramways or railways worked under the Board of Trade regulations. When the difference of potential between the rails did not exceed seven volts, what was the disturbance? We found the magnetic disturbance very considerable and the seven-volts limit was quite impossible in the neighborhood of the observatory.

Without giving you a long account of all the experiments, I will give you practically the final result. The final result of the experiments and negotiations, for which we have very much to thank our British President and Professor Rucker, for they have taken a very active part in connection with these negotiations, has been this: Within two miles of the observatory the Tramway Companies offer to cut up their line into one-mile sections—that is to say, no part of the line in that neighborhood shall be electrically continuous for more than a mile, each mile being insulated electrically from the rest of the tramway system, and that current shall be brought to the trolley wire at the middle, and taken away from the rails at the middle of each mile section. Further, that no point whatever of the rails of any of these sections shall be allowed to differ from the potential of the earth by more than *one-fifth of a volt.* We have assured ourselves by calculation and by experiment carried out in different parts of London and Great Britain, that with such a difference of potential magnetic instruments will probably not be disturbed to an amount that will be practically serious; that is to say, by an amount that will interfere with the ordinary observations carried out in a good magnetic laboratory. So I am very happy to say that the tramways, although they are about to use American plant, have looked at the matter from what I may call in this case a *non*-American point of view. And instead of relying on a supposed superior importance possessed by tramways over a study of the earth's magnetism, they have worked cordially with the Government's representatives in ascertaining what precautions must be taken to ensure immunity for the London magnetic observatories without introducing too much interference with the commercial working of tramways.

There is one other point with reference to alternating currents for electric tramways which has not been yet suggested. I was informed that one of the reasons why in the United States, alternating currents were not employed was because they found a difficulty in getting a good contact between a trolley pole and the wire when the wire had snow upon it, more difficulty, that is to say, with alternating than with direct current. Since that time, which was in 1897, certain electric railways have been constructed on the Continent of Europe which use alternating current, and it will be interesting if any one here can tell us whether any difficulty has been experienced in the winter when snow rested on the trolley wire; that is to say, more difficulty than would have been experienced had the direct current been employed.

MR. DÉSIRÉ KORDA:—When distribution in a great city is in question, the alternating current, either single or three-phase, thanks to the ease of its transformation, offers advantages over the high-tension constant current, which demands for its transformation the use of rotary transformers. As to the single-phase current, the great objection which is often opposed to its adoption, is the difficulty of adapting it to motive power, the true motor for the simple alternating current not having yet been invented. It follows, in many cases, that one prefers to adopt the polyphase current, notwithstanding the difficulty of conveniently regulating the three bridges, and of maintaining their equal tension; recourse has been had sometimes to more or less complicated systems, polycyclal, or others.

It is on the question of polyphase currents that I wish to say a few words, or rather on a case in which their advantages and their inconveniences, as compared with the constant current, as revealed in a much more evident fashion; or the case of the distribution of power in a great factory, as for example, a large sugar refinery.

Polyphase currents, as you know, gentlemen, are spreading very rapidly for the distribution of power in such establishments, owing to the simplicity of the receiving apparatus, which requires almost no repair; on the contrary, for constant currents, the collector requires many repairs, and a degree of cleanliness difficult to obtain, especially in a place like the sugar refinery I mentioned, where one constantly meets with liquids more or less viscous, and dust which settles on the collector.

Very often I have had occasion to compare the two systems in making new plans, and I have then seen their respective advantages and inconveniences. The points to which I wish to call your attention are the following:

From the point of view of maintenance and repair and for the case I have cited, there is no need for hesitation; all the advantage is with the polyphase current But here is one inconvenience which presents itself. In a factory like that I have taken for an example, it is impossible to adopt currents of high tension chiefly on account of the viscous liquids and the dust of which I spoke; the degree of cleanliness that may be relied on is only relative, and the dirtiness which results, interdicts the use of high tension currents. Also, the management of the refinery limits the electrical engineer to a tension scarcely more than 200 volts, because the efficient tensions exceeding 200 volts for an alternating current,give as their maximum value, tensions which are already beginning to be considered dangerous. Then, too, in this refinery, we have to operate numerous motors, centrifugal sugar pans, for example, of great size, and these machines require a current of great quantity, especially at starting.

It is necessary to place conductors carrying heavy currents in channels or gutters. The proprietor of the refinery, for economical reasons, spends as little as possible for the channels, and prefers bare to insulated conductors. As one cannot twist together three bare cables as could be done with insulated cables in order to avoid the effect of self-induction, one is obliged to place them as near together as possible. But there is a necessary limit to their proximity both on account of the tension and the lack of cleanliness. Here then arises a new cause of wattless current for the electrical engineer charged with the plan of installation to consider, especially if the place of origin of the current be a little distant from the location of the motors. If it is, for example, at a distance of 200 or 250 metres, the self-induction of the line begins to play an important part in a workshop of considerable size.

To the increase in the quantity of the current proceeding from the counter electromotive force of the motors is added the fall of tension proceeding from the self-induction of the line.

Besides, in most cases a special machine for exciting is not allowed; the proprietor of the establishment saying to himself that if he had employed the direct current,the same machine would have furnished the exciting power, and there would have been no need for a special exciter. Planting himself on these considerations, he asks you to make an estimate including the exciter on the same machine with the generator.

From this results a third reason limiting you so far as concerns the voltage of the system. In effect, at the moment of the strongest charge of the alternator, the engine slows up; the exciter falls off also, and when one has the greatest need of voltage, the exciter, to use a popular phrase, leaves us in the lurch. This diminution of the voltage is, in fact, as you can see, in direct ratio to the square of the diminution of the speed of the machine.

Thus there are three reasons why, for the applications of the class I have mentioned, one is obliged to choose a machine of greater capacity than one would use for a constant current.

Now let us see what remedies the day may bring forth. As you know, people have begun of late—and the Universal Exposition of 1900 made the first practical application—to concern themselves with the compounding of alternators. I think, indeed, in analogous cases, compounding is entirely indicated, and not only compounding, but over-compounding, for not only must one be able to compound the alternators, but it is necessary also to arrive at over-compounding in that which concerns the wiring in order to make headway against the loss of voltage arising from the self-induction of the motors. I believe that, in consequence, from the day when the application, of which we have had the first appearance at the Universal Exposition, shall become general, the polyphase current situation in comparison with the constant current, will grow better and better.

All that I have said has no bearing on the distribution of power by electricity in a large city; because in this case one has a high tension, and the fall of potential is proportionately very feeble; the quantity of current being small, the value of the counter electro-motive force is correspondingly feeble; besides the difficulties I spoke of will in some fashion cure themselves. But when one has a great workshop to serve, and it becomes necessary to employ large quantities of current under a low tension, these considerations I have named present themselves, and one is naturally compelled to take account of them.

Dr. F. B. Crocker:—I think now that the discussion has been opened, and the subject generally covered, that the time has come when we may confine ourselves to a few special points. The subject of our discussion is with regard to interference. I do not think that is the most important point, but as that is the subject we should apply our remarks largely to that. There are two interference effects that electric currents produce. I think they might be classified as the inductive and the leakage effects. Under the head of inductive I should include the magnetic effect, because the inductive effect is the magnetic effect, and vice versa. Now, the inductive effect of the direct current is purely magnetic, it produces only magnetic effects in its vicinity. Therefore its disturbing effect is upon magnetic apparatus in magnetic observatories or upon magnetic apparatus generally. But there are not many magnetic observatories in the world, and, as Dr. Kennelly observed, they might be relegated to a point where they would not be interfered with. It does not seem to me that the progress of the electric art ought to be influenced greatly by the existence of a few magnetic observatories, and certainly it would not be so in many places. So I should be inclined to agree with my fellow-member and dismiss that point as not very serious, to say the least.

The alternating current also has an inductive effect, viz., the production of currents in its neighborhood. It also produces a field, but that field being alternating produces no permanent effect upon magnetic apparatus. But the current inductive effect is produced solely by the alternating current, and that I should consider the more serious, because we have many more telephones or even telephone exchanges than we have magnetic observatories. As Sir William Preece has said, we can largely avoid that inductive effect by metallic circuits. But there are cases where we want wires overhead, and under those conditions we can hardly eliminate the inductive effect except by transposition of the wires, which is not a complete preventive. Furthermore, in certain cases and in smaller towns grounded circuits are used, and it seems to me that the inductive effect which produces a current in a neighboring conductor is a more serious disturbance than that of the production of a magnetic field. I think that is so at the present time, and I think it will always be so. Therefore I should say that on that account the alternating current is more guilty than the direct; in other words its disturbing effect without leakage is greater than that of the direct current. Now, the leakage effect, unfortunately, is much more serious with the direct current. The leakage of direct current is that which produces the electrolytic effect, and is the most serious interference that electric currents produce on other apparatus or other interests. But that leakage is something we can control to a great extent. The production of a magnetic field and the inductive effects are much more elusive than mere leakage. In high-tension conductors, overhead or underground, the leakage quantity is exceedingly small. It must be so. If considerable leakage occurred in an underground conductor at several thousand volts it would produce a short-circuit or a ground. But there is a leakage occurring in low-tension conductors. I think that is because we have allowed it to exist. If we insulate high-pressure conductors as well as we do, we can insulate low-pressure conductors equally well or better. I had occasion to test the underground network of New York City, many miles in extent, and the system was split up in many sections to enable this to be carried out. We found that the leakage was not excessive; it is a very small percentage of the current—considerably less than 1 per cent., as the test showed at the time. I am referring to electric lighting conductors which are not grounded. A similar result is found, I believe, by a comparison of the total output with the output that is useful. That shows that the leakage is a small quantity. In the gas industry that is not the case. A very large percentage of gas—10 or 20 per cent. in the case of

New York—is lost by leakage. But that is not true in electric distribution. So I should say that the fact that we have now in electric conductors, overhead or underground, a considerable leakage, is a temporary condition which can be overcome. I am sure electric conductors, except those purposely grounded, can be so laid that the leakage is a negligible quantity, even for long-continued electrolytic effects. Now, with the grounded trolley system, the single-wire trolley, the current must go into the earth. But there again by the use of improved methods, return feeders, and more perfect bonding, we have reduced that promiscuous flow of current through the earth, until now it is very much less than it was before, and I think it can be brought down to a quantity which is also insignificant. If it can be reduced to the figure which Professor Ayrton mentioned—one-fifth of a volt—if that were the difference of potential, it would be far below any dangerous electrolytic limit. So, apparently, the interference is not so very different in the two cases—that is to say, the alternating has a greater inductive effect without actual transfer of current, and the direct current has much more serious electrolytic effects. But those can be and have been largely overcome by more perfect construction.

I should like to say just a word on the motor question. Sir William Preece cited a certain instance where direct current machines had been replaced by alternating. I know of several other instances where alternating have been replaced by direct, so that evidence is not at all conclusive. That point alone could well occupy us for much more time than we have at our disposal. I will simply say now that so far as efficiency is concerned the two kinds of motors are almost identical. I have in my possession efficiency curves of the latest induction motors from the Westinghouse and General Electric companies, and I compared them with the efficiency curves of direct current machines of the same size, and the agreement was almost perfect; the two curves coincided almost exactly at full load and at all loads above one-third of full load. Below that the agreement was not so close.

A MEMBER:—What do you call the same size?

DR. CROCKER:—I mean in rated capacity, also in actual capacity. The agreement of the two sets of curves was remarkable and complete, except at very small fractions of full power the direct current motor has a better efficiency, but at one-half to full load the agreement was almost perfect.

SIR WILLIAM PREECE:—What was the efficiency in per cent.?

DR. CROCKER:—It depends on the size. The efficiency depends on the capacity of the machines. For example, a small machine, a one kilowatt alternating current induction motor, would have the same efficiency as a one kilowatt direct current machine between half and full power, and the curves representing that efficiency would agree exactly.

Sir William Preece:—What percentage of 100?

Dr. Crocker:—That depends on the size of the machine.

Sir William Preece:—Take one kilowatt?

Dr. Crocker:—I do not recollect that figure.

Sir William Preece:—Was it over 90 per cent.?

Dr. Crocker:—No, it was not; but we compare the two systems, and I say there is no choice in that respect, except that the direct current motor was higher efficiency at light load; at other loads the two are equal.

Now as to regulation for constant speed, the two machines are equivalent. A percentage of reduction of speed occurs when the machine is loaded from zero to full load. First-class direct and alternating current machines are equally good in that respect for constant speed; but when you regulate for variable speed the direct current motor has a great advantage over the alternating current motor. It is equal in efficiency, it is equal in regulation for constant speed, but the direct-current machine is superior for variable speed. That applies not only to stationary motors, with which I am most familiar, but it applies also to electric railway machines, and I think is equally important for stationary and for traction purposes. It is in that respect that the direct current has its advantage for power purposes over the alternating. I do not think it would be fair to the direct current or proper to this occasion to allow that point to pass unquestioned.

Mr. W. M. Mordey:—With several of our American visitors I have discussed during our meetings the question of earth drop on the return circuits of tramways, and I have found a general disposition to suppose the Board of Trade regulations restricting the drop within 7 volts was not adhered to and could not be adhered to. I have just carried out a very complete series of tests on many miles of tramways in England, and one of the things I had to investigate was that question of earth drop. I found in that system, running under the fullest load conditions, that the drop of potential never exceeded 5 volts. You will notice in tramway stations that the recording instruments which we always use, but which I think are not used in America, may momentarily indicate more than 7 volts; those instruments indicate higher momentary effects than the real value. For instance, if you suddenly switch one of those instruments on to a steady pressure of 6 volts it will usually swing to about 10 volts. One of the differences between English and American practice is, I think, apart from the question of scale, that great attention has been given to this question of earth drop and to the continuous recording of what is happening. The Board of Trade regulations are strictly enforced. I am sure the result has been good. I hope in this discussion we shall obtain from our American visitors some actual quantitative results arising from electrolysis. The real point which I think was intended to be brought out was whether or not electrolysis, quite apart from other questions, would not be a determining factor in the development of systems of supply, at least where earthed conductors were used.

I will ask you to bear in mind the one and only absolute cure for all troubles of this sort, whether direct or alternating currents are used—the insulation of both conductors. I expect to find it applied in the future in all railway cases and in all conduit cases, whether for direct or for alternating current. Quite apart from the avoidance of electrolytic effects it has many advantages. To comply with Board of Trade regulations we have to use boosters and great quantities of copper to assist the return circuit. There would be no objection to 25 or 50 volts—or even more, instead of 7—if we had not to consider electrolysis. We could, if we wished--and if it were economical to do so—have as big a drop on our return as on our trolley line if we used an insulated return, and we should get rid of bonding and of sparking at dirty rails and of electrolysis. Information as to the results of the working of the double trolley system at Cincinnati, where it is or has been employed on a large scale, would be of great assistance to us. We should like to know if, in America, in your conduit or railway work, you are making any efforts to avoid the objectionable earth return.

Whether in the future there will be any preponderating system still seems quite uncertain. It may be the system is going to be alternating for transmission and direct for distribution, but I cannot help thinking that ultimate simplicity will lead to the use of alternating currents for almost everything, at least where we have long-distance transmission or large areas. In railway work where we begin with alternating currents, the simplicity of transformation will probably ultimately lead to the use of alternating throughout. There is, however, much to be said for Mr. Leonard's system, with his rotary converter on the car, if direct currents have any part. My own feeling, in spite of present fashions in England, is that sooner or later we shall have in all large systems the alternating current right through. I believe the rotary transformer is a make-shift, to be cleared away sooner or later for railway work; it is quite unnecessary for lighting and only indispensable for electrolytic work.

Some of you may go on to Switzerland from here and may see the examples of alternating work there. You will see the Burgdorf-Thun Railway and the Engelberg and Jungfrau Mountain railways, where many questions are disposed of. If you can start a train on a mountain rack railway you can start one anywhere.

We have, during the last few days, seen the Central London Railway, and highly appreciate the facilities afforded us by the company during our visit. But all of us who have had to do with the estimating of engineering work will have felt that if all the cost of those sub-stations—their static and rotary transformers and so on, their first cost, their maintenance, their working cost in power and labor—could be realized and put into conductors, we should have, for that case at least, a simple system which would be safer and probably more economical in first cost, certainly in working cost afterwards.

The question of capacity has been referred to. It is more serious in alternating underground work than is generally realized. I recently had to investigate some difficulties due to capacity on a system of two hundred and fifty miles of underground cables in St. Petersburg. There is really much less difficulty than is generally supposed in overcoming most of the effects of capacity of such mains. I wish I had time to say more on the subject, but must leave it to an opportunity which I hope may be granted later.

I should like to refer to one "existing interest." I mean the interest of the public and of the scientific laboratories and observatories. There can be no question that ultimately these institutions will have to be removed from the centers of large populations where there are great applications of electricity, unless the methods adopted in those institutions can be so ordered as not to be interfered with by such applications. Fortunately we have at the Board of Trade a striking object-lesson. As far as I know, the Board of Trade electrical standards laboratory is the only electrical institution in England which is legally obliged to be accurate. It is laid out in such a way, the responsible officials say, that although they are in the heart of London they do not mind what electrical applications are made in London; their arrangements are such that they can carry on their work with the accuracy demanded by law without any reference to what is going on outside. That does not touch the question of measuring the magnetism of the earth. But surely that should be measured where it is the magnetism of the earth and not that due to the application of electricity to the use and service of man. There was a case in London of an institution, whose work I would not for a moment depreciate, where the influence of that institution was exerted successfully to prevent what would have been a very great convenience to the population of London, the running of an underground electric railway. It is difficult to speak calmly of such an action. There was no sort of proportion between the two interests; yet, though the object of the scheme was so excellent, the smaller interests were allowed to stand in the way of the benefit and the convenience of the population of London.

Mr. C. O. Mailloux :—The subject has been so well discussed —it has been nearly exhausted already—that there is very little to be added. There is one point only which I think has not yet been fully discussed. In our country we would take a broader interpretation of the topic of discussion than is being taken here. The effects produced upon certain industries oftentimes effect the feasibility of the industry, and in this connection I have been able to note the practical difference between the two systems, and the one which in fact determines the feasibility of either one, or its want of adaptability, according to the case. One of the important points, which it seems to me has been neglected, is the influence of the power factor in the case of the alternating current. My colleague, Professor Crocker, has pointed out quite clearly the similarity in results obtainable between the alternating and the direct-current motors. He has also pointed out that at constant speed they work quite alike. But he has neglected to note that the influence of the power factor on alternating currents is a matter of importance. As we know, when the electromotive force of the source of supply of a direct-current shunt-wound motor varies, the magnetic field of the motor varies, but that has the effect of merely changing the armature current to an extent necessary to maintain the speed; so that although there is speed fluctuation, it is not so great as when the electromotive force varies in the case of the alternating-current motor, because the speed is in this case a higher function of the electromotive force. In our country we have several isolated plants which assume the dignity and importance of central stations. It is not uncommon for us to have isolated plants of one thousand to three thousand horse power, which distribute energy over a zone of about half a mile radius. It is under such conditions that these difficulties are to be noticed. I remember an instance where a certain process for manufacturing coffee was employed, the electric current for which was furnished from a power station which also supplied lights to the district. It was found that owing to the enormous wattless current produced at the starting of the motors, on many occasions the line and even the generators would be overloaded, the result being that the current supply was cut off by the fuses blowing off, and that the machinery which was used in that coffee mill was put out of action, oftentimes at critical moments, when the stoppage meant great loss. The alternating-current motor system became absolutely inadmissible in this case from that circumstance, and had to be abandoned. One of the great objections, as you know, to the alternating-current motor of to-day is the fact that it takes such a large current at the time of starting. Its large wattless component is a serious matter, affecting, as it does, the working capacity of a line where the motors are constantly stopping and starting. Where all the motors are running together at an approximately constant load and at constant speed, the problem is simple, and there are no industrial reasons why the alternating current should not be placed upon an equal footing with the other. But where the motors are constantly stopping and starting, and especially where the distribution of power is constantly changing, and also where you load certain feeders more than others, the disturbance becomes very important. It has to be seriously taken into consideration by the designing engineer in laying out the plant. I have had occasion to install a plant in a sugar refinery which required 2,000 H. P., and it was decided to adhere to continuous-current motors partly for these reasons, and also for the reason that in cases where variable speeds are required, and where the machinery is required to run at intermediate speeds, there can be no question that the direct-current system is at the present time the most suitable, if not indeed the only feasible one. I wish in this connection to speak of the pertinent remarks made by our French colleague in reference to one of the features, one of the industrial conditions, which oftentimes influences the selection of systems. I refer to the cost of the wiring. It is true that to-day, at least for the larger distributing conductors in buildings, and within a short radius, as well as for underground purposes (where we are obliged to use concentric or twisted conductors), the cost of the wiring is necessarily much greater than in the smaller branches and networks, such as the local lines or mains which run to individual motors. In our country the problem is, to some extent, solved, since we use iron conduits any way for these lines. Our insurance regulations prescribe, indeed practically compel, the use of iron conduits for the smaller lines, and, usually, we have two conductors, twisted or concentric, as the case may be, laid in iron conduits, whether the circuit work be used for direct or for alternating currents; but in the case of the larger conductors the arrangement need not necessarily be the same in both cases. With alternating current we must still use a twin or duplex conductor laid in an iron conduit, to keep down the reactance drop. With direct current there is no reactance, and we are not compelled to use twin conductors. It is often found to be very much cheaper to use two separate conduits, and two ready-made single conductors (especially in the case of the larger feeders or mains), than to use one single conduit very much larger in size and a cable specially made at relatively great expense. The mechanical difficulties in laying the larger conduits, their greater obtrusiveness and the greater space occupied by them, especially at bends, turns, offsets, etc., would be sufficiently objectionable even if they did not, as they do, in most cases, make the cost relatively greater.

PROFESSOR SILVANUS THOMPSON:—We have had no observations whatever upon the relative interference of alternating and continuous currents on board ship. It is of absolutely vital importance that there shall be no interference with the magnetism of the compass, and yet, extraordinary as it may seem, almost all ships that are equipped with the electric light are equipped with continuous current apparatus. I never could understand why that was. Some of the earliest vessels had alternating currents on a three-wire system, with the skin of the ship serving as a middle wire, but this system was succeeded by one with the very worst kind of continuous-current generator which could be put on board, viz., the bi-polar. I hope to see a complete revulsion in ship-fitting from this plan.

No reference has been made to the somewhat greater danger of fire that exists where conductors are carried through damp places if those conductors are served with continuous current. Electrolysis beginning at some leak will develop a current which eventually heats and destroys the insulation at that point, and thus originates a fire. With an alternating current you are less likely to have that occurrence. On the other hand, I suppose switch-makers will tell us that alternating switches are more expensive than continuous. No one has mentioned that while for arc-lighting admittedly there is some advantage in using continuous currents, for glow-lamps there is an advantage in using the alternating current. Not that there is any higher efficiency—that fallacy has long been disposed of—but if you use a continuous current for glow-lamp purposes, and the distribution is to take place over any large area, it becomes absolutely necessary to go to the high-voltage lamps working 200 to 250 volts. Now, any one who has taken the trouble to measure the reputed efficiency of high-voltage glow-lamps will know how inferior they are to the 100-volt glow-lamps; things which are supposed to be taking 3½ watts per candle being found actually to take 6, 7 and 8 watts per candle. I think there will be a great revulsion when the facts are known about the inefficiency of high-voltage glow-lamps. I prefer to have 50-volt glow-lamps; they are better in every way and last longer. This is impracticable with a continuous current, but with the alternating current it can be done where there are house-to-house transformers; and so, using low-voltage lamps, you can work to a much greater distance with alternating than with a continuous current.

I was sorry to hear Dr. Kennelly rake up the fallacy of there being a greater danger to persons from the alternating than from the continuous current. But that is a revival of a bit of the old electro-politics. When people wanted to damn the prospects of alternating currents and show how much better they were for electrocution, this was the line they took. I hope those arguments have disappeared. I think there is some evidence that the alternating current is not so dangerous as the continuous current; that the shock which is given by the alternating currents throws backwards the unfortunate person who receives it, and does not contract his muscles upon the conductor in the way that a continuous current does. The researches of Prof. H. F. Weber must not be overlooked. I prefer to leave that question to M. d'Arsonval, who understands these electro-physiological effects better than we electrical engineers.

Professor Ayrton raised the question of the electrolysis produced by the alternating currents. Might I point out that the question whether alternating current will, in any given circumstances, produce continuous electrolysis depends very largely upon the question of the relative area of the electrodes employed and the density of the current; because whether gas is disengaged at that area or not during the period depends on the density to which that gas accumulates and whether it is given off. In fact the question whether the polarization becomes irreversible or not is very largely a question of scale.

Lastly, I will draw attention to certain points connected with electric traction on a large scale. I re-echo the suggestion of Mr. Mordey that it is well worth while for one who has not seen those electric railways in Switzerland to visit them, and to see how admirably the three-phase current is adapted for starting trains under the most severe circumstances possible. It is known from the experiments of Professor Carus-Wilson that the difficulty of the acceleration of the motor at starting is after all imaginary, and that it requires an extra percentage of current is also a fallacy. Every motor started upon a load takes more current than when running on that load, and this is true also of the tri-phase motor. The current required to produce rapid acceleration is even more important than the starting-torque, and the three-phase system, instead of being worse, is distinctly better.

We have had in London several recent object-lessons on electric traction. One of them has been, from one point of view, a gigantic success, but also a total failure. Little more than a year ago we were told that one of our millionaire railway companies had put down a sum of, I think, £30,000 to have experiments tried upon the underground railway. I referred nearly a year ago to this supposed experiment, and pointed out that the one experiment which was wanted for electric traction was to ascertain whether a three-phase motor arrangement would be better than a continuous one. We knew pretty well, but we wanted it tested, we wanted a verification. That experiment has not yet been tried. There were called in several engineers of the highest distinction, and they were aided by the constructional ability of Messrs. Siemens Brothers. But the only thing which has been tried, notwithstanding that all the resources of a great railway company stood behind the experimentation—I say it before Sir William Preece's face—all they have succeeded in doing is merely carrying out on a large scale what was done at Gross Lichterfelde, by Siemens and Halske, fifteen years ago, viz., establish the fact that you can drive by the continuous current, using conducting rails put beside the ordinary rails. The London press has pronounced this experiment to be a perfect success. I regard it, on the contrary, as an abject failure, inasmuch as it gave us no further information.

Lastly, if you are going to have, as I think we shall have, trains running at 100 or even 150 miles an hour, driven electrically, there will be no chance of success if we have to depend upon a motor which has got a commutator upon it. I speak of a new growing interest, viz., exceedingly rapid transit, and I venture to say that for exceedingly rapid transit the only chance of possible success is to take advantage of that which is the finest thing of all in electrical engineering, the perfect flexibility and adaptability to requirements afforded by the current when that current is an alternating one.

Mr. H. Ward Leonard:—I have a fair acquaintance with what can be accomplished with the continuous current as regards large starting-torque with a small amount of energy, and have given considerable attention to the operation of large motors which have to be started under very heavy loads, and operated at different speeds and reversed.

I have lately seen one of the recent installations employing three-phase motors upon railway work in Switzerland, and I must say that when the car was started it seemed to me as though there were about one donkey-power doing the accelerating. It did not convey the impression to my mind of being able, with moderate power, to produce the heavy starting-torque required for the rapid acceleration which is such an important factor in electric railway work and many other important applications of electric motors.

Perhaps my views on this point are a little biased, but it seems to me that when we consider large railway motors the most important points are: rapid acceleration, small starting energy, perfect and simple control and ease of reversing, and the restoration into the circuit of the energy at present wasted upon the brakes.

We find the possibility of obtaining all of these points in the continuous current to a degree to which there is no promise as yet in the alternating current.

When we consider the question of electrolysis, we are met with difficulties in attempting to use a continuous current in the ground return circuit, which seem insuperable except by capital expenditures which are entirely uncommercial.

When we wish to transmit very large amounts of energy over the long distances which are desirable, we all agree that the alternating current is the only suitable one for the purpose.

These considerations have, for many years past, made me believe that we ought to use the alternating current for the generation and transmission of our energy, and that we should have upon the moving vehicle some means of transforming the alternating current into a continuous current of controllable E.M.F., and that we should use this continuous current of variable E.M.F. for operating the propelling motors at the variable speeds required in practice.

These arrangements would give us large starting-torque with a small consumption of energy, and even in the case of the largest motors will give perfect control at any desired speed and simplicity in reversing. It eliminates all difficulties due to the electrolytic action of the continuous current in the ground circuit. It gives us the power to employ motors of practically unlimited power at practically unlimited distances for railway and other variable speed uses, and entirely eliminates the expensive and inefficient sub-stations of to-day.

It seems to me that the electric railway is the application of electric power which is going to exert the determining influence upon the methods of using electric energy in the future, especially the railway motors of very large size; and it seems to me a significant fact that, after twelve years of development by the leading engineers of all countries, there are no alternating current motors exhibited at this exposition for railway service or any other duty having similar requirements.

PROFESSOR PERRY:—Mr. Carl Hering, M. Mascart and I waive our right to say anything on this question, although we could, of course join heartily on one or other side. I beg to say that we think it better to have no vote upon this discussion as it is an incomplete discussion—one which is adjourned. The specimen sent by the Board of Trade will be on view in our room in the British Pavilion.

At the conclusion of the discussion, brief references to cetrain objects possessing special or novel interest in the electrical sections of the International Exposition were made successively by M. Hospitalier, Major-General Webber, Mr. Gavey, and Mr. Hering.

REPORT OF DELEGATION OF AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS TO THE INTERNATIONAL ELECTRICAL CONGRESS HELD AT PARIS, FRANCE, IN AUGUST, 1900.

To the Executive Committee and Council of the
American Institute of Electrical Engineers.

Gentlemen :

The following is the report of the delegates officially representing the American Institute of Electrical Engineers at the International Electrical Congress held in Paris, in August, 1900.

It had been voted, at the regular Council meeting of March 28th, 1900, that the President of the Institute in office at the time of the holding of the Electrical Congress should be the official delegate of the Institute to that Congress; and that he should be authorized to appoint such additional delegates as he might deem advisable. Under this decree, Mr. Carl Hering became the official delegate, by his election to the Presidency in May, 1900; and in June, 1900, he appointed the following additional delegates :

Dr. W. E. Goldsborough, Wm. J. Hammer, Dr. A. E. Kennelly, C. O. Mailloux, Dr. M. I. Pupin.

The appointments were announced formally by letter from the Secretary, under date of June 26, 1900.

At the close of the opening session of the Electrical Congress, in Paris, on the 18th of August, President Hering called together in conference all that could be found of the members of the American Institute of Electrical Engineers there present. On information that Dr. Pupin and Dr. Goldsborough would not be present, the President appointed Dr. F. B. Crocker and Mr. B. J. Arnold, as delegates in their places. The delegation then elected Dr. Crocker as Chairman, and Mr. Mailloux as Secretary. Attention was called to the fact that President Hering and Dr. Kennelly were also official delegates of the U. S. Government, and that the United States would be allowed only three votes, same as France, England, Germany, and other large countries (all smaller countries being limited to two or even to one) in the "Chamber of Official Delegates," or that portion of the Congress which was alone to pass upon international questions, such, for instance, as the adoption of new units. It was decided that the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS should preempt and control at least two of these three votes, if possible. (It actually controlled all three votes, when the time came.) Dr. Kennelly was unanimously chosen to represent the delegation and the INSTITUTE, before the Congress, in all matters pertaining to units. Mr. Mailloux was chosen to act as interpreter and spokesman for the delegation, when necessary; and he was also appointed as substitute for Dr. Kennelly in the Chamber of Official Delegates, at any and all meetings of said body which might take place after Dr. Kennelly's departure, in case he could not remain in Paris until the close of the Congress. It was also decided that it was desirable to arrange for and to hold, if possible and at an early date, a joint informal conference of the American and English delegations, for the purpose of exchanging views on the question of units, and also, if expedient and practicable, of securing concerted action by the two delegations. The delegation meeting adjourned, subject to call of the chairman of the delegation. It was not found necessary to call any other formal meeting, the delegates being able to confer together before or after or during the session meetings, without difficulty.

It is proper to point out here that the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS had, as a body, virtually committed itself on the question of units and nomenclature, to a certain definite policy, which was set forth in the report of its Committee on Units and Standards, as presented and adopted at the last General Meeting, at Philadelphia, in May, 1900. This Report had been formulated, originally, with the intention that it should serve, if need be, as a formal statement, before the Electrical Congress, of the attitude of the INSTITUTE on the questions of units and nomenclature. A French translation of this Committee Report had been made, and a thousand copies had been printed, which were distributed to all the members, at the opening meeting of the Electrical Congress, and which were also obtainable at all the succeeding sessions. This report was properly regarded by the delegation of the INSTITUTE as constituting the programme of its official policy. The efforts of the delegation were therefore to be aimed at securing international cognizance of and action upon recommedations of this report.

The joint conference with the English delegates took place on Monday, August 20th, and the aforesaid report was there presented for consideration. The discussion to which it gave rise was both long and varied: but the conference nevertheless adjourned without having reached any definite conclusion or understanding regarding joint action on any of the many topics considered. The result was far from encouraging, more especially as much opposition to the adoption of any new units or to any change in nomenclature was brought to light. It was soon found, moreover, that many of the prominent European delegates were unfavorable to the programme of our delegation, and that the task of the delegation would be a difficult if not a hopeless one.

The work of the Electrical Congress was apportioned among five sections, one of which included three divisions, making a total of seven departments; each section having a French president and three or four foreign vice-presidents, among which were three members of our delegation as follows: Dr. Kennelly, in Section I (Methods and Apparatus for

Measurements, etc.); Mr. Mailloux, in Section II, Division A (Production and Utilization of Electricity); Mr. Hering, in Section II. Division B (Electric Lighting). At the first meeting of Section I, Dr. Kennelly was also appointed on the Special Committee on Units (with Prof. Hospitalier as chairman), to consider and report upon the general question and subject of units and nomenclature.

Dr. Kennelly worked very hard, both in committee and out of it, to secure the acceptance and adoption of the measures recommended by the INSTITUTE. It became evident, however, that the propositions or recommendations presented in behalf of the INSTITUTE could not be all reported favorably by the Special Committee of Section I, and that some of them must be sacrificed. The official report of this Committee (of which a translation is appended to the present report), gives the recommendations which the committee finally decided to adopt and which its chairman (Prof. Hospitalier), reported to Section I, at the last formal meeting of this Section, in the morning of August 24th. As the text of the report indicates, Dr. Kennelly had been unable to induce the committee to consider the matter of revising or rationalizing the units. He succeeded, however, in securing action favoring the adoption of two units (one for magnetic density, the other for magnetic flux), both of which were on the programme of the INSTITUTE delegation; he secured the recommendation of the name ("Gauss") first advocated by the INSTITUTE for one of these units.

The Special Committee Report gave rise to an animated discussion, before Section I. The adoption of names for the unnamed units, especially for C. G. S. units was strenuously opposed by many of the members, including Prof. Mascart, who presided at this meeting of Section I. In the absence of Dr. Kennelly, who had left for America, Mr. Mailloux addressed the meeting and presented the views and arguments of the INSTITUTE delegation in favor of the adoption of the Committee Report. He took occasion, in the course of his remarks, to call special attention to the fact that the "Gauss" was already accepted and recognized by the INSTITUTE; that it was already in practical use in America; that the necessity for and convenience of this unit was generally admitted; and that it only lacked international sanction to pass into universal use; and, finally, that the want of official recognition of these two units might retard, but would not likely prevent, their general use and ultimate adoption. The report of the Special Committee was finally adopted by Section I., each portion or recommendation thereof being separately discussed and voted upon. The vote of the meeting on the question of units had the effect, however, of slightly modifying, or rather of supplementing, the recommendation of the Special Committee Report, so far as one of the units (the unit of magnetic flux) was concerned. The question whether the two new units should be "C. G. S. units," or "practical" units had caused much contention and difficulty, there being partisans on both sides. (Even the INSTITUTE delegates were not all of the same opinion on this question). The Committee Report, therefore, represented a compromise between the factions, on this question, for while it specified the kind of unit (C. G. S.), for which it proposed the name "Gauss," it did not specify the kind of flux unit for which it proposed the name "Maxwell." It merely recommended that a name for "a unit of magnetic flux," whose value was to be defined and fixed at some future congress. The kind and the value both became "fixed," however, by the motion carried before Section I, which conferred the name Maxwell upon a C. G. S. unit of magnetic flux.

In the afternoon of the same day (August 24th) the general meeting of the official delegates of the various governments took place, according to programme. The three delegates officially representing the United States government on this occasion were all members of the INSTITUTE, namely, Mr. Hering, Mr. Mailloux, and Major Millis (U. S. A.), and consequently all three of the votes allotted to the United States were at our disposal. Your delegation deems it a duty and a pleasure to state that the work done and the results accomplished at this meeting, by these delegates, are highly creditable to the dual constituency which they had the honor to represent. It is due wholly to their efforts that the "Gauss" and the "Maxwell" have become international units. A skillfully planned attempt was made at this meeting to prevent the matter of units from being formally presented before and being acted upon by the official delegates. This strategem, which was part of the tactics of the systematic opposition on the part of certain individuals to the adoption of new units, was both foreseen and foiled by the American delegation. Had it succeeded its effect would have been tantamount to "sidetracking" the two new units, by preventing them from receiving the formal, official consideration of the only portion of the congress which was qualified to give them international character and standing. This is made clear by the explanation that, in the section meetings, there were no restrictions whatever of the voting privilege. All the members voted on all questions; they voted, however, as private individuals solely, and not as national delegates. Hence, any action taken, as the result of a vote in a section meeting, really signified nothing more than an expression of opinion by individuals. This opinion might have a certain significance or weight, according to the prominence or the authority of the individuals influencing its expression. Nevertheless, it could have no international character or value, for the simple reason that the members of certain nationalities preponderated in the attendance at the section meetings. In the chamber of official delegates, on the other hand, the voting privilege was accorded to each nation, in a restricted and definite manner, as the result of an apportionment calculated to give to each nation a fair representation, proportionate with its importance. Hence, any action based on a vote in the chamber of official delegates implied the approval or at least the assent of the nations, especially if the decision were unanimous.

The INSTITUTE delegates felt that the new units would not have had a clear title or proper credential as "international" units, without the formal endorsement or ratification of the chamber of official delegates. It was for this reason that it determined to force the issue, on realizing that the session was about to adjourn *sine die*, without taking official action on the new units. Mr. Mailloux, as spokesman for the American delegation, addressed the meeting and called attention to the anomalous position in which the two new units would be placed if the official action of the chamber of delegates were omitted; and he cited, as a precedent, the fact that the "henry" was officially adopted by the chamber of delegates at the Chicago Congress. A long and exciting discussion resulted. An idea of what the American delegation here accomplished may be formed from the statement that it literally forced the question of units into consideration before the chamber of official delegates; that it moved the formal adoption of the two new units recommended in the Special Committee Report; that it held its ground in a stormy debate precipitated by this motion, and lasting over an hour, at first alone, and for much of the time unaided, and in the face of determined opposition, not only from the delegates, but also from the chairman; and, finally, that it ultimately overcame the opposition and secured the passage of the motion with practical unanimity. It may be added that, having attained its purpose,—the official adoption of the new units—it generously aided its opponents to attain theirs,—the passage of a resolution declaring electrical energy to be "property," and entitled to legal protection as such.

At the closing (general) session of the Congress, on Saturday (August 25th), Mr. Mailloux, speaking for the delegation, took occasion to formally express its thanks in behalf of the INSTITUTE and of the American Electrical Engineers for the cordial reception and the many pleasant courtesies accorded to our members during the Congress by our French colleagues, more especially those having taken part in the organization and management of the Congress; and he extended a hearty invitation to the delegates and electrical engineering bodies of all countries to visit America next year, on the occasion of the Pan-American Exposition at Buffalo.

This session was the last official gathering of the Congress, and with it the work of the INSTITUTE delegation ended.

Respectfully submitted,

NEW YORK, Nov. 21, 1900.

F. B. CROCKER, *Chairman*,
BION J. ARNOLD,
CARL HERING,
C. O. MAILLOUX, *Secretary*,
WM. J. HAMMER.

THE EUROPEAN TRIP OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

SECRETARY'S REPORT.

Although the suggestion that the INSTITUTE should hold a meeting in Europe was made several years ago, there was at the time considerable doubt as to whether a sufficient number could be expected to attend. When the date of the International Electrical Congress of 1900 was announced the Council was of the opinion that this event together with the Paris Exposition would make it possible to organize a joint meeting with the Institution of Electrical Engineers of Great Britain, and on November 22, 1899, a committee of three was appointed, with instructions to ascertain about how many members would attend such a meeting if called. It was at that time thought that twenty-five members would constitute a fair representation. It will be readily understood that it was a difficult matter to unite upon a date which would be acceptable to a very large percentage of the membership. Again, the length of time consumed and the expense of the journey were factors which had to be taken into consideration. It was evident at the outset that no reduction of rates could be obtained, so the members were required to make their own plans as to transportation. The suggestion for a joint meeting was favorably considered by the Council of the Institution of Electrical Engineers and the plan and scope of the meeting were undertaken by it. Past-President Martin, a member of the Committee on Papers and Meetings, being in Europe in April and May, was authorized to make such preliminary arrangements as were necessary on behalf of the INSTITUTE. Through the courtesy of Commissioner Peck and Director F. H. Drake, Mr. Martin was enabled to secure space for headquarters in the Electrical Department of the Exposition Buildings, also permission to hold the joint meeting in the United States National Pavilion. The dates finally fixed upon for the various events were governed by the period selected for the Electrical Congress, August 18th to 25th.

A very complete and interesting programme for the entertainment of our members in London was arranged by the Institution of Electrical Engineers, which was opened in the happiest manner by a river party on the Thames, Sunday, August 12th. Many of our members were already in Paris at that time, but several of them made the trip to London and participated in the welcoming exercises which had been so carefully prepared. The first gathering at Paddington Station, in London, for the Thames trip made up a joint party of seventy, including about thirty representatives of the INSTITUTE. After a railway journey of about an hour, Henley-on-Thames was reached, where three electric launches and one steam launch, gayly decorated with British and United States flags intermingled, awaited the arrival of the electrical engineers. The weather was simply perfect, and the pleasures of the day, eagerly looked forward to, can only be properly appreciated by those who had the good fortune to participate. A preliminary run of ten miles, nearly to Shiplake, was first made, returning to Henley, where a bountiful luncheon had been provided by our hosts at the Red Lion Inn. Before leaving the tables, President Perry, of the Institution of Electrical Engineers, formally welcomed the guests, and proposed the toasts of "The Queen" and "President of the United States of America." He then announced as his invention the plan of calling upon two proposers and two respondents to the toasts which followed. Mr. Alexander Siemens and Mr. Mark Robinson proposed "Our American Guests." President Hering responded and pleasantly acknowledged the hospitality of our English hosts, in which he was ably seconded by Mr. W. J. Hammer, who made a very entertaining and amusing address. The party then returned to the boats, which started down the river on the main trip of the day. The beautiful English landscape, changing at every turn in the historic Thames, was enlivened by the thousands of pleasure seekers, young and old, of both sexes who were enjoying a day's outing upon the water and along the shores. Probably no other river in the world is so thoroughly utilized for out-of-door enjoyment, and it may be readily understood by those who have witnessed the hearty interest shown, why England has in the past been pre-eminent in aquatic sports. Among the novel and interesting features of the trip was the passage through the locks, where pleasure craft of all descriptions were bunched closely together while passing from one level to another. The river trip ended at Maidenhead, where tea was served at the Thames Hotel. Carriages there awaited the party, and after a few minutes' drive the railway station was reached, and with the return to London a day of unalloyed pleasure was ended.

On Monday, August 13th, various works of interest were visited, the most important, because of its novelty, being the Central Underground Railway, operated by electricity. This is the first instance in London of a transportation line on which no attempt is made to classify passengers and where a uniform rate of fare prevails. The equipment is largely American. Locomotives are used instead of motor cars. The service is good and the tunnel is clean and well ventilated. The stations are conveniently located and accessible. The principal objection appears to be that the facilities are not equal to the traffic during the hours of maximum travel. The power station and one of the sub-stations were visited. The Electrical Standard Laboratory of the Board of Trade, the telegraph department of the General Post Office and the Davies Street Station of the Westminster Electric Light Corporation were also visited by members having special interest in those institutions.

Monday evening our members were entertained at a complimentary banquet by the President, Council and Members of the Institution of Electrical Engineers at Princes' Restaurant, Piccadilly. The perfect arrangements which were so apparent on the provious day were predominant on this occasion, and the best of feeling prevailed, largely induced by the excellence of the dinner. Many ladies from England and the United States were present and added greatly to the enjoyment of the evening. The chair was occupied by President Perry, who proposed the toasts of "The Queen" and the "President of the United States." Following the precedent established at the Red Lion Inn luncheon, the President called upon Messrs. H. H. Cunynghame, C.B., and J. S. Raworth to jointly propose the "United States," which was responded to by President Carl Hering, Past-President F. B. Crocker and Mr. C. O. Mailloux. Secretary Pope and Mr. W. M. Mordey were invited to propose the toast of "Electrical Engineering," to which Dr. Silvanus P. Thompson and Past-President A. E. Kennelly responded. In conclusion, Mr. H. Ward Leonard proposed the health of President John Perry, who in reply complimented

Secretary McMillan very highly upon the excellent manner in which he had made all the necessary arrangements, to the entire satisfaction of all.

Tuesday, August 14th, was devoted to a visit to the Government Dock Yard at Chatham. The party assembled at Victoria Station and, after a railway trip of about an hour, was driven to the Yard, and placed under the guidance of Major G. A. Carr, R.E. The various objects of interest visited included the latest type of ironclad, the department of electrical equipment, and the training school of the signaling corps, which included an exhibit of the heliograph, which proved of such important service in the South African war. The visiting members were entertained at luncheon by the Royal Engineers Club, Maj. Gen. Sir Thomas Fraser, K.C.B., C.M G., R.E., presiding. Later in the afternoon they were the guests of Lady Fraser, at a lawn party.

A joint committee was formed of representatives of both the Institution of Electrical Engineers and the American Institute of Electrical Engineers to take charge of the preliminary arrangements and details of the Joint Meeting at Paris. This committee was made up as follows;

Representing the I. E. E.	*Representing the A. I. E. E.*
John Perry, F.R.S., President,	Carl Hering, President,
W. E. Ayrton, F.R.S.,	William J. Hammer,
H. H. Cunynghame, C.B.,	A. E. Kennelly,
R. K. Gray,	C. O. Mailloux,
W. M. Mordey.	R. W. Pope.

On Wednesday, August 15th, the combined British and American party assembled at Charing Cross Station and started for Paris at 10 A.M., arriving at about six o'clock. There they again separated according to the hotel arrangements they had made.

Thursday, August 16th, the joint meeting, which was officially presided over by President Perry, of the Institution of Electrical Engineers, and President Hering, of the American Institute of Electrical Engineers, was held at the United States National Pavilion, quai d'Orsay, 140 engineers being present. The topic presented for discussion was "The Relative Advantages of Alternating and Continuous Currents for a General Supply of Electricity, Especially with Regard to Interference with Other Interests." The discussion was opened by Mr. Ferranti and continued by Mr. Bion J. Arnold, Sir William H. Preece, Dr. A. E. Kennelly, Prof. W. E. Ayrton, M. Desiré Corda, Dr. F. B. Crocker, Mr. W. M. Mordey, Mr. C. O. Mailloux, Dr. Silvanus P. Thompson and Mr. H. Ward Leonard. A complete, revised stenographic report of this discussion appears in the Transactions. After the close of the discussion, Messrs. Hospitalier, Webber, Gavey and Hering gave brief descriptions of the most interesting electrical exhibits, and in the afternoon several parties were formed, and were conducted through the Exposition by those who were familiar with the exhibits.

It having been determined by the members who were present in Paris to tender a reception to the officers and members of the Institution of Electrical Engineers and their French colleagues, a committee consisting of Messrs. Hammer, Mailloux and Pope, acting with the President, undertook to make the necessary arrangements. The only available date appeared to be Monday, August 20th, Commissioner Peck extended the courtesy of the United States National Pavilion for that purpose All arrangements were made after the adjournment of the meeting on August 16th. About three hundred invitations were issued, and the reception appeared to be a success. The attendance was one hundred and eighty, including representatives from most of the European nations.

On Friday, August 17th, by special invitation of Mr. Clerault, Chief Engineer of the Western Railway of France, the members were afforded an opportunity of visiting its interesting three-phase power station and other features of its electrical traction work. The arrangements for this trip were made by Mr. Coster, of the Westinghouse Electric and Mfg. Co. A "five o'clock tea" tea at the British Royal Pavilion followed, where Colonel and Mrs. Jekyl received the members with true English hospitality. The use of this Pavilion was given by H.R.H. the Prince of Wales and the British Royal Commission.

On Wednesday, August 22d, the President and Council of the Institution of Electrical Engineers, by the kind permission of H. R. H. the Prince of Wales and the British Commission, gave a reception at the British Royal Pavilion, which was largely attended and was a very interesting occasion.

On Saturday, August 18th, the International Electrical Congress convened, at which the INSTITUTE was represented by the following delegation: Dr. F. B. Crocker, Chairman, Bion J. Arnold, W. J. Hammer, Carl Hering, A. E. Kennelly and C. O. Mailloux.

Although the work of our delegation is reported elsewhere, it is a pleasure to state briefly that while its members did not accomplish all that they hoped for, yet they really did very well, as there was at one time a fear that their efforts would all be in vain. Through the preliminary work of Dr. Kennelly, and the successful presentation by Mr. Mailloux of the INSTITUTE's case in the Chamber of the Official Delegates of the various governments officially represented, the main portion of the suggestions reported by the Committee on Units and Standards was finally officially adopted by the Congress, as shown in the formal report of the delegation.

The Congress adjourned on August 25th, and was followed by a banquet the same evening on the Eiffel Tower. On this occasion nine different nationalities were represented, speaking eight different languages, which led a gentleman present to remark that the Eiffel Tower had been converted into a veritable "Tower of Babel."

Respectfully submitted,
RALPH W. POPE, *Secretary.*

APPENDIX.

ACTION OF COMMITTEE ON UNITS.

INTERNATIONAL ELECTRICAL CONGRESS, PARIS AUGUST, 1900.

The appointment of this committee was proposed by Prof. E. Hospitalier at the first session of Section I, August 20, 1900.

Prof. Hospitalier was appointed chairman, with power to choose and appoint the full committee. The committee was made up as follows:

Prof. W. E. AYRTON,	Great Britain.
Prof. M. DE CHATELAIN,	Russia.
Prof. DORN,	Germany.
Prof. E. GERARD,	Belgium.
Prof. L. LOMBARDI,	Italy.
Dr. KENNELLY,	United States.
Mr. DE FODOR,	Hungary.
Mr. DE HOOR TEMPIS,	Hungary.

TEXT OF REPORT.

(Translation.)

REPORT TO M. THE PRESIDENT OF SECTION I.

At its meetings of August 21st and 22d, 1900 the Committee on Units, appointed by the First Section of the International Congress of Electricity adopted the following conclusions:

The Committee shall take into consideration only propositions whose nature does not involve any modifications in the decisions of the previous Congresses.

The Committee does not believe that there is any actual necessity of giving names to all the electromagnetic units.

Nevertheless, in view of the use of practical measuring apparatus giving directly the magnetic field density in C. G. S. units, the Committee recommends attributing the name of "Gauss" to this C. G. S. unit.

The Committee proposes to attribute the name of "Maxwell" to the unit of magnetic flux, whose value is to be defined ulteriorly.

Dr. Kennelly, in the name of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, withdraws the propositions made concerning prefixes and the rationalization of electric and magnetic units.

PARIS, August 22, 1900. E. HOSPITALIER, *Chairman.*

LIST OF INSTITUTE MEMBERS AND FRIENDS AT LONDON AND PARIS

AUGUST 18-25, 1900.

Adamson, D.
Arnold, B. J.
Ball, W. D., and Mrs. Ball
Bernard, E. G., and Mrs. Bernard
Bradley, C. S., and two sons
Brown, W. D.
Buckingham, C. L.
Clark, W. J.
Coster, M.
Crocker, F. B.
Donner, W. H.
Doubt, Thomas E.
Edmands, I. R.
Ganz, A. F.
Garfield, A. S.
Hammer, W. J.
Heinrich, R. O.
Henry, I. W., Mrs. Henry and son
Hering, Carl
Hollister, J. M.
Kennelly, A. E.
Lansingh, V. R.
LeBlanc, Chas
Leonard, H. Ward, and Mrs. Leonard
Lloyd, Herbert
Lloyd, R. McA.
Lohmann, R. W. and Miss Lohmann
Macfarlane, Alex.
McVey, W. D., Wichita, Kan.
Mailloux, C. O., and Mrs. Mailloux
Millis, Major John, and Mrs. Millis
Mordey, W. M., and Mrs. Mordey
Mix, E. W.
Mullin, E. H.
Oolgardt, J. J.
Olivetti, C.
Phillips, L. A.
Pope, R. W.
Potter, Henry Noel
Preece, Sir W. H.
Smith, Jesse M., and Mrs. Smith
Smith, Oberlin, and Mrs. Smith
Stephens, Geo.
Swan, J. J.
Thompson, S. P.
Thurnauer, Ernst
Townsend, Fitzhugh
Weaver, W. D., and Mrs. Weaver
Welles, Francis R.
West, Julius H.
White, J. G., Mrs. White and son
Zalinski, Capt. E. L.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, September 26th, 1900.

The 146th meeting of the Institute was held this date at 12 West 31st Street, and was called to order by President Hering at 8:20 p. m.

The Secretary:—At the meeting of the Executive Committee this afternoon it was decided to hold our monthly meetings hereafter on the fourth Friday of each month instead of the fourth Wednesday. This change was brought about for two reasons. One is that sometimes there is difficulty in getting papers ready on account of the half holiday on the Saturday preceding; but the most important one is that we have found upon inquiry that very often we might have the pleasure of the attendance of members from out of the city who can hardly come during the middle of the week, but who could come on Friday and have Saturday and Sunday to return home. This change of date of course will be given on all the notices which go out before the meetings as usual, and you will be reminded of the fact of the change.

It was also arranged, although this is entirely unofficial, that on the night of the meeting as many as possible as are obliged to take their dinner in the city, will arrange to meet at the same restaurant, and the announcement of the dinner and time will be given on the postal cards. This will be entirely distinct from the meeting, and has been done for the reason that it is for the benefit of members who may thus get together in a social way before the meetings whenever possible.

The President:—We will now proceed with the reading of the paper of the evening. The paper is by Prof. Henry S. Carhart, of the University of Michigan, on the "Imperial Physico-Technical Institution in Charlottenburg" As Prof. Carhart is not present the paper will be read by Dr. Sheldon.

[See page 469, August and September issue.]

A paper presented at the 146th Meeting of the American Institute of Electrical Engineers, New York, September 26, 1900. President Hering in the Chair.

THE IMPERIAL PHYSICO-TECHNICAL INSTITUTION IN CHARLOTTENBURG.

BY HENRY S. CARHART.

I. HISTORICAL.

Through the courtesy of Professor Kohlrausch, President of the Reichsanstalt, and the Curatorium or governing body of the institution, the writer was accorded the privilege of working in the Physikalisch-Technische Reichsanstalt as a scientific guest during the last few months of 1899. An unusual opportunity was thus afforded of learning rather intimately the methods employed and the results accomplished in this famous institution for the conduct of physical research, the supply of standards, and the verification of instruments of precision for scientific and technical purposes.

It is well-known that the Reichsanstalt is situated in Charlottenburg, a suburb of Berlin just beyond the renowned Thiergarten. The buildings occupy an entire square, the larger part of which, valued at 500,000 marks, was the gift of Dr. Werner Siemens. In making this gift, which was offered in land or money at the option of the government, Dr. Siemens declared that he had in mind only the object of serving his fatherland and of demonstrating his love for science, to which he avowed himself entirely indebted for his rise in life. The gift was made as a stimulus to the government to establish an institution for physical research. The kind of institution desired had been amply described in suitable memorials prepared by himself, Professor von

Helmholtz and others of scarcely less distinction. The first memorial bears date of June 16, 1883. It relates to "The Founding of an Institution for the Experimental Promotion of Exact Natural Philosophy, and the Technical Arts of Precision." It points out the need of such an institution, details the benefits likely to accrue from it, lays great stress on the intimate relation existing between scientific investigations and their application in the useful arts, and sets forth somewhat in detail a plan of organization. The memorialists had in mind at that time a "Physico-Mechanical Institution," but in a memorial of the following year (March 20, 1884) the title was changed to the one which the institution now bears—"Physikalisch-Technische Reichsanstalt." From this second memorial it is learned that the first steps toward the furtherance of exact science and technical precision in an institution to be founded and maintained by the State, were taken as early as 1872. This movement had the support of the crown prince, the late Emperor Frederick, and the matter was taken in hand by Count von Moltke as chairman of the Central Bureau for Metrology in Prussia. He called together a commission near the end of the year 1873, and in the following January this commission reported a series of propositions for the improvement of the scientific mechanic arts, and of instruments of precision. These propositions formed the foundation for a memorial on the same subject to the Chamber of Delegates of the Prussian Government in 1876. The result was that appropriate rooms were set aside in the new building of the Technical High School in Charlottenburg for the organization of an institution for the cultivation of the arts of precision.

The general plan of the Reichsanstalt was adopted in 1887, and an appropriation of 868,254 marks was made and spread over the budget for three years. The main building for the first or scientific division was completed in 1893. The second or technical division was housed in a portion of the Technical High School till the buildings for this division were completed in 1897. All departments of activity of the Reichsanstalt are now accommodated on the square facing on March Strasse in Charlottenburg. They include the division for pure scientific research, mechanical measurements of precision, electrical measurements and instruments, the measurement of large direct and alternating currents and electromotive forces, the optical department, the department of thermometry, the department of pyrometry, and the department of chemistry. To these as auxiliaries should be added the power plant and the workshop.

II. ORGANIZATION.

The two divisions into which the Reichsanstalt is divided correspond to the two paramount objects which the founders had in view, viz., research in pure science, and the cultivation of precision in the technical applications of science. The same idea is embodied in the very name of the institution—The Imperial Physico-Technical Institution. If the sole purpose of the Anstalt had been the promotion of improvements in the mechanic arts, in engineering, and in instruments of precision, the first or scientific division would still have been essential to secure the ends sought. All the applications of science rest on the foundation of pure scientific discovery. The creation of new and improved methods and instruments for physical measurements requires the most exhaustive and painstaking investigations as a preliminary to a steady and confident advance. The practical value of research in pure science is no longer in question. The wise founders of the Reichsanstalt made no mistake in coupling an institution for the promotion of technical precision with one for the prosecution of research in physical science.

The governing body or Curatorium of the Reichsanstalt is appointed by the Emperor. At its head is Herr Weymann, Imperial Privy Counsellor. The function of the Curatorium is the appointment of the officials and the general management of the institution. The chief officer of the Reichsanstalt is the President, and the most distinguished physicist of the realm is sought for this position. Helmholtz was taken from the University in Berlin to become the first incumbent of the office; after his death in 1894, his successor as professor of physics in the University, Professor F. Kohlrausch, became his successor as President of the Reichsanstalt.

The President, who is at the same time director of the first division, is held responsible for the successful work of the Reichsanstalt. All other officials are therefore subordinate to him. In his absence the duties of his office devolve upon the Director of the technical division. Subordinate to the Director of this second division are the professors, associates, and assistants of various grades. A professor in charge of a department has the direction of all those employed in it, including a skilled departmental mechanician.

The specific duties of the President may be briefly enumerated. He must lay before the Curatorium at its annual meeting the following:

1. A report on the work executed in both divisions.
2. The plan of work for the undertakings to be carried out the ensuing year.
3. Propositions relative to the money to be expended for scientific and technical work; also for salaries and remunerations.
4. Propositions relative to the rank of permanent associates and assistants; also relative to the bestowal of places to work in the Reichsanstalt as scientific guests.

FIG. 1.—President's House.

He takes a vote on the propositions in 3 and 4, and reports the conclusions of the Curatorium to the government for approval. It is also the duty of the President to sign vouchers for all payments, and he is held responsible for the proper expenditure of the money appropriated for the maintenance of the institution.

The different functions of the two divisions composing the institution are defined in rather broad terms. It is the duty of the first division to carry out physical investigations requiring more uninterrupted time on the part of the observer, and better accessories in the way of instruments and local appliances, than private individuals and laboratories of institutions for teaching as a rule can offer. These investigations shall be carried out partly by officers of the Anstalt and partly, under their oversight, by scientific guests and voluntary workers. By scientific guests in general are meant the holders of scientific positions in the German empire, who wish to prosecute scientific researches, the plan of which they have submitted, and for which they have not at home the necessary appliances. They must be recommended by the State in which they reside and must be accepted by the Curatorium.

FIG. 2.—Building for Large Current and Machinery.

Young men may be accepted as voluntary workers who have proved their ability by scientific publications. They will undertake researches which have been determined upon by the Curatorium or the Director; or they may investigate subjects which they themselves suggest, and which appear to the Director to be practicable and worthy of execution. The scientific results obtained must be published only at the discretion of the authorities of the institution, who reserve also the right to publish them in the researches of the Reichsanstalt. Provision is made that voluntary workers shall not use the institution for private ends nor to obtain patents.

The second division of the Reichsanstalt is placed under a Director, who is subject to the higher authority of the President. Such a Director was considered necessary on account of the special work of this division, as well as because of the intimate relations into which it is brought with many persons engaged in industrial pursuits. He should therefore not only be a scientific man but should at the same time have some technical knowledge of the applications of science. Under the Director are placed the permanent heads of the subdivisions of the technical department, one having the oversight of thermometry, one of optics, two of electricity, and one of mechanical measurements of precision. Along with these and of the same rank and compensation is the director of the workshop. Under him at present are eight mechanics, and the shop is provided with the finest tools for the execution of the most exact work required by the institution. For

Fig. 3.—Main Building, Division I.

example, it has a circular dividing engine that cost $2,500. The founders of the Reichsanstalt foresaw the necessity of such mechanical aids for the furtherance of the exact work to be undertaken. They wisely concluded that such special constructions and new types of instruments as they might require from time to time could be more conveniently and more cheaply built in their own shop than by private instrument makers.

III. Cost and Maintenance.

The following are the official accounts of expenditures for the grounds, buildings, furniture and instruments for the two divisions, to which are added the yearly expenses:

Fig. 4.—Main Building, Division II.

Division I.

1.	Acquisition of ground, the gift of Dr. Werner Siemens	500,000	M.
2.	For erection of buildings:		
a.	Main Building	387,000	"
b.	Machinery Building	50,000	"
c.	Administration Building	100,000	"
d.	President's House	99,254	"
e.	Grading, Paving, etc.	10,473	"

f.	Paving Half of Street	30,274 "	
g.	Building for Battery	8,500 "	
3.	Fittings and Furniture	58,000 "	
4.	Equipment of Machinery and Instruments	32,810 "	1,325,810 M.

DIVISION II.

1.	Acquisition of Ground	378,106 M.	
2.	Erection of Buildings :		
a.	Main Building	922,000 "	
b.	Laboratory Building	218,000 "	
c.	Machinery "	180,000 "	

FIG. 5.—Main Building. (In part.)

e.	Dwelling for Officials	140,000 "	
f.	Additional Improvements	348,000 "	
3.	Fittings and Furniture	108,300 "	
4.	Equipment of Machinery and Instruments	471,390 "	
		2,760,796 "	
	Less reduction for 1895–96	47,500 "	2,713,296 M.
	Divisions I and II together		4,039,106 "

The annual expenditures for 1889 were as follows :

1. Expenditures for Salaries and Laborers	206,604 M.
2. Miscellaneous Articles, Experimental Work and care of Buildings	127,000 "
Total	333,604 "

The receipts for calibrating instruments, testing materials, verifying standards and the like now amount to about 40,000 M. annually. This sum should be deducted from the yearly expenditures, leaving a net sum of about 300,000 M.

In round numbers the Reichsanstalt has cost $1,000,000, and the annual appropriation for its maintenance is $75,000.

IV. Results.

A very pertinent inquiry is, what are the results of all this expenditure? Might not more good be accomplished by state aid to some existing technical school or university? The results attained must be set by the side of the objects which the founders of the institution had in view in order to ascertain whether the sequel has justified their predictions. In the memorials to which reference has already been made, Professor von Helmholtz and Dr. Werner Siemens pointed out the advantages likely to accrue to Germany from the maintenance of an imperial institution for research, which should at the same time assume the cognate function of fixing and certifying standards of mechanical and physical measurements. Attention was drawn to the fact that other countries, notably England, had enjoyed great renown in science because of the brilliant researches and discoveries of some of her scientific men, who had the good fortune to be possessed of leisure and large private means, and the scientific spirit to devote them to investigations demanding both as a *sine qua non.*

These conditions the memorialists declared were lacking in the fatherland. Her scholars who had the enthusiasm and the capacity for exact scientific investigation possessed neither the private fortune to devote to it, nor the uninterrupted time for the execution of the work. They were to be found among the men engaged in teaching, but their professional duties absorbed their time to such an extent that only an inadequate residue remained; and even that little was divided into fractions too small to admit of the sustained and continuous attention which any important investigation demands.

It was further pointed out that if the government would supply the conditions favorable to scientific discovery, the men could be found whose work would reflect great credit on the state, while the interaction between pure science and its applications to arts and manufactures would put Germany in the forefront of scientific renown and of the intelligent application of science to useful purposes.

It was further urged by von Helmholtz that the brilliant investigations of Regnault and other French physicists many years ago should now be repeated with the superior methods and instrumental appliances available at the present time. These investigations drew the attention of the scientific world to France and made it the focus of scientific interest. Her instrument makers, even up to the present, have reaped a rich reward in foreign orders for instruments made eminently desirable and almost indispensable by these distinguished French investigators.

Other problems, too, needed solution, problems forced to the front by modern requirements and discoveries. The applications of electricity, for example, present new questions for science to answer, while the interests of the consumer at the same time call for some form of control by the State of the instruments employed in fulfilling contracts. The very units in which such measurements are made need to be authoratively settled—a task demanding the highest manipulative skill in experiment and the most refined appliances which experience can suggest and money purchase.

The German government admitted the force of these considerations and made splendid provision, both for pure science and its technical applications, by founding the Imperial Institution at Charlottenburg. The results have already justified in a remarkable manner all the expenditure of labor and money. The renown in exact scientific measurements formerly possessed by France and England has now been largely transferred to Germany. Formerly scientific workers in the United States looked to England for exact standards, especially in the department of electricity. Now they go to Germany. So completely has the work of the Reichsanstalt justified the expectations of its founders, and so substantial are the products of this already famous institution that other European nations are following Germany's example. Great Britain has already made an initial appropriation for a National Physical Laboratory to be organized on a plan similar to that of her Teutonic neighbor. Mr. R. T. Glazebrook, who has long served as Secretary of the Electrical Standards Com-

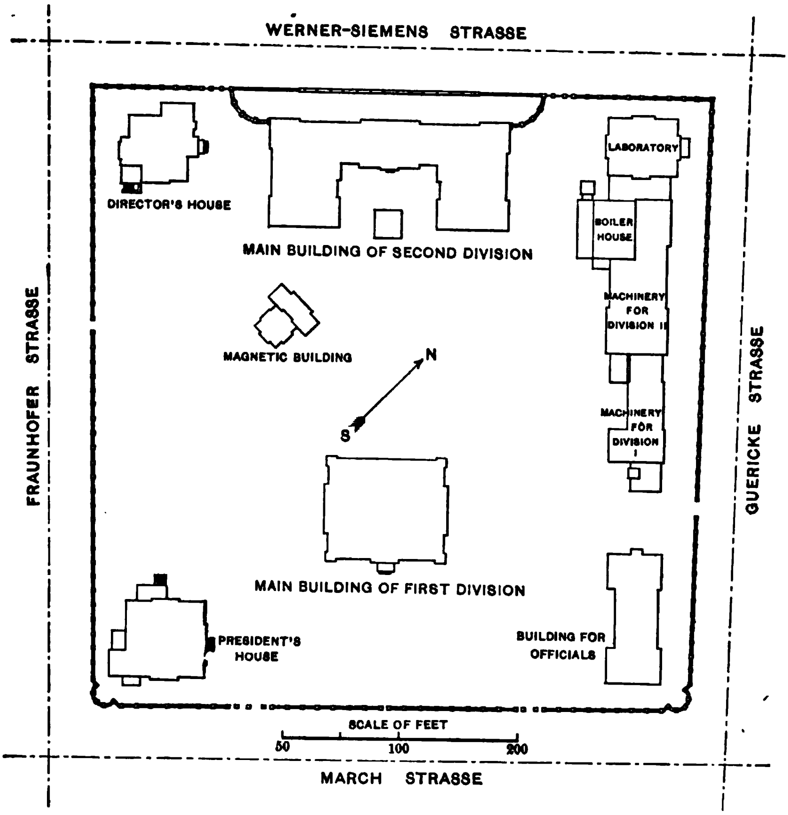


FIG. 6.—General Plan of Ground and Buildings.

mittee of the British Association for the Advancement of Science, has been appointed Director and has entered on his duties. The new institution will absorb the old Kew Observatory, and other buildings will be added at once for the extension of the functions of this Observatory so as to include the larger enterprise contemplated in the establishment of the new National Laboratory.

Russia also has a number of large and well equipped laboratories in connection with her Central Bureau of Weights and Measures. One of these is devoted to the verification of instruments for electrical measurement. It employs fourteen men and the budget is about $45,000 per annum.

France is also moving in the same direction. The great service of France in fixing standards of length and mass has long been freely recognized by the civilized world. But her national bureau for this purpose is now considered to be too limited in scope to solve the new problems presented. Quite recently a committee of learned men from Paris, under the leadership of Minister Bourgeois, visited Charlottenburg for the purpose of examining into the working of the renowned institution located there. Professor Violle, one of the most illustrious physicists of the French capital, accompanied the committee. What better evidence of the success of Germany's great institution can be demanded than the consensus of favorable opinion among those best qualified to judge that its fruits are already of the highest order of merit, and its imitation by other European nations—the sincerest form of flattery.

It would not be just to form an estimate of the success of the Reichsanstalt without taking into account its scientific publications. These are numerous and of great value. Most of the reports of work done are made public with official sanction in various scientific and technical journals. During the past year thirty such papers have been published. The detailed accounts, however, of the most important undertakings thus far completed are contained in three quarto volumes of investigations. Among those contained in the first two volumes may be mentioned papers pertaining to thermometry and to units of electrical resistance.

The investigations in thermometry comprise such topics as the influence of the glass on the indications of the mercurial thermometer, division of the thermometer and determination of the errors of division, determination of the coefficient of outer and inner pressure, determination of the mean apparent coefficient of expansion of mercury between 0°C. and 100°C. in Jena glass, and investigations relating to the comparison of mercurial thermometers.

Four papers of exceptional value relate to normal standards of electrical resistance. They are, the probable value of the ohm according to measurements made up to the present time, the determination of the caliber correction for electrical resistance tubes, the normal mercury standard ohm, and the normal wire standard ohm of the Reichsanstalt. When one recalls that the ohm as a practical unit of measurement is defined in terms of the resistance of a specified column or thread of mercury, it will readily be seen that the work done at Charlottenburg in this particular field is fundamental in character and of the most universal importance.

In passing it is worthy of remark that all the standard resistances designed and constructed at the Reichsanstalt are carefully compared with the mercurial standards early in each year. This custom is in accordance with the action taken by the electrical standards committee of the British Association at Edinburgh in 1892, when the mercurial standard was definitely adopted. At this meeting of the committee, representatives of American, French and German physicists (including von Helmholtz) were invited to sit as members. The methods employed in these comparisons and the forms of the standards are original with the Reichsanstalt. The new forms and methods admit of a combined accuracy and convenience not previously attained.

In addition to the work done in electrical resistance, the investigation of the silver voltameter and the electromotive force of standard Clark and Weston cells has been highly productive of useful results for the other two fundamental electrical measurements. Much remains to be done in this latter direction, for the electromotive force assigned to the Clark and the Weston cell, even in the latest report of the Reichsanstalt, is derived from measurements by the silver voltameter, while the electrochemical equivalent of silver is in doubt to a greater extent than the electromotive force of the Clark cell.

Perhaps the best indication of the valuable work of the Reichsanstalt is to be found in the annual "Thätigkeitsbericht." This report of the year's activity is published in the "Zeitschrift für Instrumentenkunde," and the reprint for 1899 forms a pamphlet

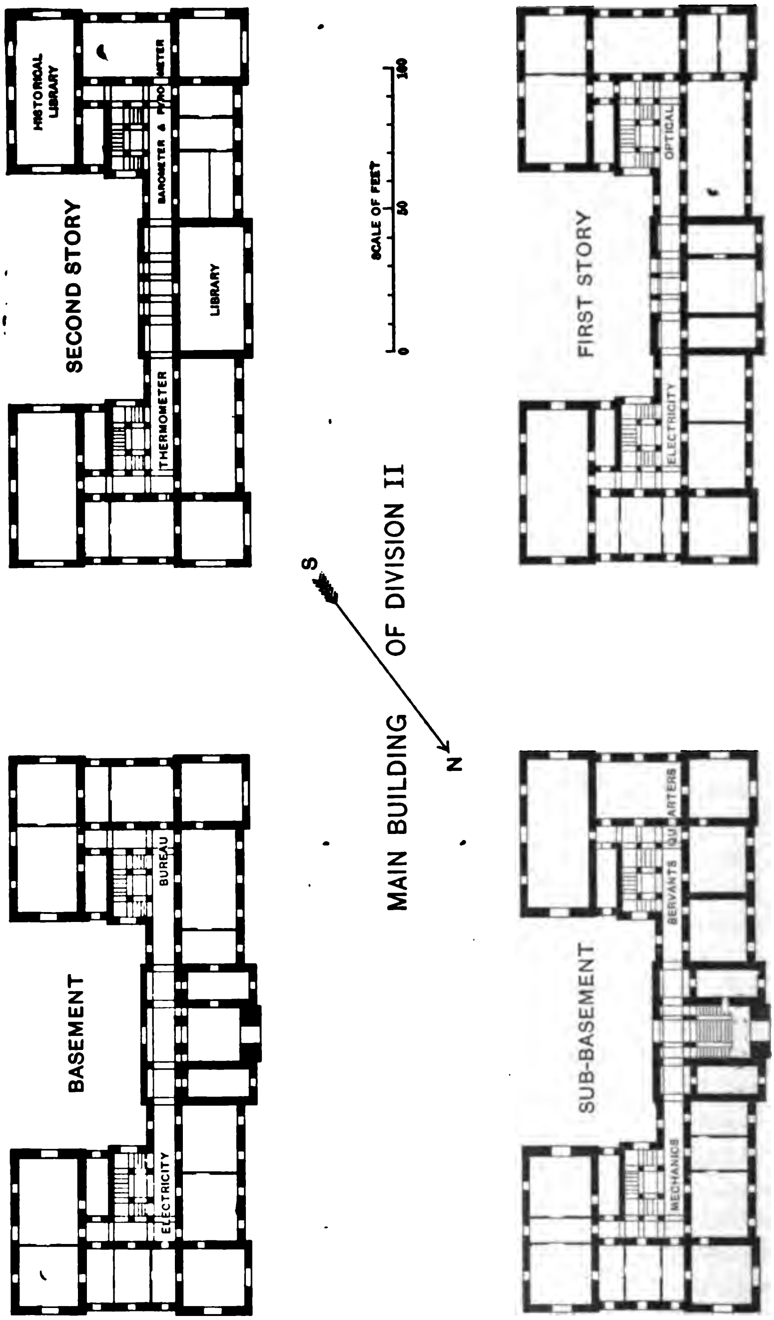


Fig. 7.—Floor Plans of Main Building. Division II.

of twenty-five large, closely printed pages. The following abstract will convey some impression, though an imperfect one, of the extent of the work accomplished:

FIRST (PHYSICAL) DIVISION.

I. *Work in Heat.* Determination of the density of water between 0°C. and 40° C.

Determination of the pressure of water vapor at low temperatures.

Determination of the pressure of water vapor near 50° C.

Investigation of thermometers for temperatures between 100° and 200° C.

Investigation of the nitrogen thermometer with a platinum-iridium bulb for very high temperatures.

Investigation of thermometers for low temperatures.

Determination of the thermal and electrical conductivity of pure metals. (These determinations are to be extended down to the temperature of liquid air and up to 1000° C.)

Investigations with the Fizeau-Abbe dilatometer.

Investigation of the transmission of heat through metal plates.

II. *Work in Electricity.* Comparison of the normal wire resistances of Divisions I and II.

Determination of the capacity of an air condenser.

Comparison of the standard cells of Divisions I and II.

Determination of the conductance of water solutions with a higher degree of accuracy than has been attained hitherto, especially with very dilute solutions.

III. *Work in Light.* Investigation with electrically heated black bodies.

Proof of Stefan's law between 90° and 1700° absolute temperature.

Determination of the relation between the intensity of light and the temperature.

Measurement of radiation in absolute measure.

Determination of the distribution of energy in the spectrum of black bodies.

Determination of the distribution of energy in the spectrum of polished platinum and other substances ; also their reflective power.

SECOND (TECHNICAL) DIVISION.

I. *Work of Mechanical Precision.* Investigation of the errors of length and of the division of 300 scales, tubes, etc.

Coefficient of expansion of 18 bars, tubes and wires.

Verification of 86 tuning forks for international pitch.

Construction of a new transverse comparator.

Study of the variations of angular velocity of rotating bodies.

II. *Electrical Work.* Calibration of direct current apparatus, 188 pieces.

Calibration of alternating current apparatus, 58 pieces.

Examination of other electrical apparatus, 76 articles.

Examination of accumulators, primary elements and switches, 87 articles.

Examination of insulating and conducting materials and carbons, 23 articles.

Installation of storage cells for a current of 10,000 amperes.

Installation of small storage cells for an electric pressure of 20.000 volts.

Installation of alternating current instruments for measuring potential difference up to 500 volts and current up to 100 amperes.

Examination of 29 samples of alloys for specific resistance and temperature coefficient.

Examination of 126 samples of insulating materials with an electric pressure up to 800 volts.

Verification of single resistances, 128 samples.

Calibration of 83 resistance boxes, compensation apparatus, etc., containing 1158 single resistances.

Comparison and verification of 133 standard cells—111 Clark and 22 Weston elements.

Determination of the ratio Clark 15° C. to cadmium 20° C., and Clark 0° C. to cadmium 20° C. with a large number of standard cells.

Examination of 21 samples of dry and storage cells.

Calibration of 15 galvanometers to measure high and low temperatures with thermal elements.

Magnetic examination of 25 samples of iron and steel.

Investigation of the difference between the continuous and the discontinuous magnetization of steel.

Investigation of the influence of repeated heating on the magnetic hardness of iron.

III. *Work Relating to Heat and Measurement of Pressure.* Calibration of 18,777 thermometers.

Examination of 4 safety appliances and benzine lamps.

Calibration of 317 thermal elements.

Verification of 9 manometers and 22 barometers.

Testing of 190 samples of apparatus for petroleum investigations.

Testing of 3210 samples of safety rings and plugs.

Testing of 23 samples of indicator springs.

IV. *Work in Light.* Testing of 149 Hefner lamps for photometric purposes.

Testing of 189 incandescent lamps.

Testing of 143 gas and other lamps and adjunct appliances.

Investigation of the relation between the temperature of sugar solutions and their rotatory power on polarized light.

Investigation of quartz plates for the examination of sugars.

Determination of 100 points in the normal Ventzke scale for sodium light.

Especially careful collection of sugars from Germany, Austria, France, Russia and North America for the investigation of specific rotatory power.

V. *Work in Chemistry.* Continuation of the study of the solubility of important salts.

Electrolysis of platinic chloride and the migration of the ions.

The quantitative determination of metallic platinum.

Investigation of liquids for use in thermometers to measure low temperatures.

In addition to the above work attention is drawn to the fact that there are two institutions for calibration and certification of thermometers under the control of the Reichsanstalt, one at Ilmenau and the other at Gehlberg. During the last ten years the institution at Ilmenau has tested in round numbers 350,000 thermometers.

The number of persons employed in the Reichsanstalt the past year was 87.

V. A LESSON FOR US.

If Germany has found it to her scientific and industrial advantage to maintain the Reichsanstalt, and is proud of what it accomplishes; and if Great Britain is so impressed with the success of the institution that she has decided to imitate it, it is surely the part of wisdom for the United States to move in the same direction. It is therefore very gratifying that at the suggestion of Secretary Gage a bill was introduced in the last Congress to establish a National Standardizing Bureau, and that the Committee on Coinage, Weights and Measures reported unanimously and strongly in favor of its passage. So great is the importance of this movement from the point of view of science, of national pride, and of the higher interests of industrial pursuits, that the effort so happily begun, to secure suitable legislation should be repeated with redoubled force and enthusiasm. Some of the reasons for making this effort one does not need to go far to seek.

In the first place the scientific interests to be served are certainly as great as in any other country in the world. Science is cultivated here with increasing assiduity and success. We are no longer content to follow in the footsteps of European savants and modestly repeat their investigations. Original work of a high order is now done in many American universities; but the difficulties under which university instructors prosecute research are even greater here than in Germany, and we are still compelled to go to Europe for most of our standards. As a result, inventions of an almost purely scientific character originating here have been carried to perfection in the Reichsanstalt, and Germany gets the larger part of the credit. I need only instance the Weston standard cell, which has been so fully investigated at the Reichsanstalt, and the alloy "manganin," which the same institution employs for its standard resistances after a searching inquiry into its properties. Both of these are the invention of Mr. Edward Weston, one of the Past-Presidents of this INSTITUTE. So long as there is no authoritative bureau in the United States under Federal control, and presided over by men commanding respect and confidence, we must continue "to utilize the far superior standardizing facilities of other governments." It is true that science knows no nationality, but the scientific workers of any nation can serve their own country better if they are not compelled to obtain their standards and their best instruments from distant parts of the globe. America has the cultivation in physical science, the ability on the part of her investigators, and the inventive faculty to do work in a national institution that we shall not be ashamed to place by the side of Germany's best products. The establishment of a national institution for physical and technical purposes can not fail to foster a vigorous and healthy growth in science, to which we already owe so much of our national prosperity and renown.

In the second place Congress should be stimulated to take action because of national pride. It is not creditable for a capable and self-reliant nation to continue to depend on foreign countries for its standards of measurement, for the certification of its instruments, and for the calibration of its normal apparatus for precise work. Different departments of our Government and offices under its control must at present appeal to foreign bureaus for the certification of their standards and instruments of precision. The first day the writer spent at the Reichsanstalt he was consulted with reference to an extended correspondence between the Director of the technical division and the officials of the Brooklyn Navy Yard relative to the calibration of a large number of incandescent electric lamps for use in our Navy department. The spectacle of a Government bureau going to a foreign imperial institution for standards in an industry whose home is in the United States is a humiliating one. Yet the proceeding was entirely proper and justifiable because there is in this country no standardizing bureau for the purpose desired. Are the representatives of the American people willing to have this state of affairs continue?

Again, the higher interests of the industrial utilization of scientific knowledge require the establishment in Washington of an institution similar to the Reichsanstalt and in no degree inferior to it. We are an inventive people and may justly claim renown in the prompt and efficient utilization of the discoveries in physical science. It is highly improbable that a practical limit has already been reached in the field of applied physics. We are not estopped from making further discoveries. Still it may be affirmed with confidence that the most important and promising work to be done, except in the rare instances in which genius makes a brilliant discovery, will consist in the more perfect adaptation of known physical laws to the production of useful results. It is precisely this field which has not been extensively cultivated as yet in the United States. We have explored the surface and presumably gathered the largest nuggets and the most brilliant gems. To increase the output we must now delve deeper and scrutinize more closely. To drop the metaphor, what will be required for future preeminence is the more intensive and exhaustive study of the scientific conditions in the industrial utilization of physical laws. This study will require the best talent of our technical schools, aided and supported by an authoritative national institution, itself far removed from patents and commercial gains, but jealous of our national renown and eager to co-operate with manufacturers for the sake of national prosperity.

Germany is rapidly moving toward industrial supremacy in Europe. One of the most potent factors in this notable advance is the perfected alliance between science and commerce existing in Germany. Science has come to be regarded there as a commercial factor. If England is losing her supremacy in manufactures and in commerce, as many claim, it is because of English conservatism and the failure to utilize to the fullest extent the lessons taught by science; while Germany, once the country of dreamers and theorists, has now become eminently practical. Science there no longer seeks court and cloister, but is in open alliance with commerce and industry. This is substantially the view taken by Sir Charles Oppenheimer, British Consul-General at Frankfurt, in a recent review of the status and prospects of the German Empire.

The Reichsanstalt is the top stone of Germany's scientific edifice. It has also contributed much to her industrial renown. It is necessary to cite only her manufactures involving high temperatures, such as the porcelain industry, to appreciate the help afforded by the Reichsanstalt. The methods and instruments elaborated there for the exact measurement of high temperatures constitute a splendid contribution toward industrial supremacy in those lines. The German government sees with great clearness that the Reichsanstalt justifies the expenditure made for its maintenance, not by the fees received for certifications and calibrations, but by the support it gives to the higher industries requiring the application of the greatest intelligence. In this connection it should be thankfully acknowledged that the services of this imperial establishment are placed at the disposal of foreign institutions of learning with the most generous liberality. The charges for calibration are only about one-fourth the expense incurred in making them, but the support thus given to German makers of instruments of precision, by increasing their foreign orders, is deemed a sufficient return for the services rendered.

Discussion.

The President:—The subject is now open for discussion. It is unfortunate that Prof. Carhart is not present to answer questions, but it would nevertheless be interesting to hear the views of the members present on the subject of the paper. I had the pleasure of visiting this Reichanstalt only about a week ago, and if I can answer any questions I will be glad to do so; my visit was only a very short and hurried one.

I am very glad that Prof. Carhart presented this paper to the Institute, and that he brought out so forcibly in the last section, the need of a similar one in this country. It is certainly humiliating for us in this country to have to go to a foreign institution to have our instruments standardized. There is no reason at all why we should not do exactly the same kind of work here. The expense of conducting this creditable institution, seems to me to be exceedingly small. It is also somewhat humiliating for us that the Weston standard cell, which was invented here, was not appreciated by the world until after it had been investigated by the Reichsanstalt. The same is true of manganine, which now seems to be the standard resistance material in the Reichsanstalt; it seems, in fact, that the manganine standard resistances in that institution are depended upon more than the mercury ohms.

The Reichsanstalt, as Professor Carhart has described to us, is divided into two quite distinct departments, the one for research and the other for what might be called commercial standardization. Prof. Carhart in his paper puts more stress on the first department, that is, the department for research. As a matter of fact, however, the second department is by far the larger. I found that, as far as labor and expenditures are concerned, they stand about as one to three; that is to every man in the research department, there are three men in the standardizing department; the expenses, it seems, are about in the same proportion.

I was interested in the standard of light which that institution has adopted, the Hefner amyl-acetate lamp. They seem to be quite well satisfied with it now, and say that it is more accurate as a standard than the usual measurements that are made with it on the photometer, and therefore it is a sufficiently good standard. They use it altogether, and it has been adopted in Germany as the standard both by the gas and by the electrical industries. This standard can be reproduced by constructing it according to scale, that is, according to measurements, it does not necessarily have to be calibrated; that is, if constructed exactly according to specifications one can be sure that it will give one candle without the necessity of calibration; for very accurate work they are calibrated by the Reichsanstalt. In our country we seem to have no real standard of light. It seems that at one of the large lamp factories in our country, the standard used was handed down through many years, in the form of incandescent lamps.

If we in this country should start a similar institution, I think it would be better to lay more stress on the second department of the Reichsanstalt, that is, the calibrating department, than on the research department, at least at first. I think the first department should follow the introduction of the second, and not precede it, because the second department will yield results at once, and will supply something which is much needed in this country.

I might add that I inquired whether thev preferred the Weston cell to the Clark cell, and I found that they not only preferred it, but found it to be very much better. It seems that the Weston cell is now replacing the Clark cell altogether, due, of course, to the well known fact that the temperature coefficient is negligibly small. It was amusing to notice that nowhere did they call it the "Weston cell," as they did not seem to like to admit that it came from America. It is always called the "cadmium cell" there, although the other is called the "Clark," and not the "zinc cell."

Dr. Samuel Sheldon:—Mr. President, I think that we as a scientific body, and any other scientific body, would strongly favor the founding in this country of an institution of this character. Certainly, if France, or if England, or if Russia, who are so near to the standards of the Reichsanstalt, can feel that it is necessary for them to found such an institution, we, who are over the ocean, who have such troubles in our Custom Houses, and who have such long delays in getting returns from the other side, ought to favor it. We, however, ought to consider that outsiders, and those who are not interested particularly in science, must be made to take an interest, before the object can be attained, and I hope some action will be taken before long, even further than that which has been already taken, to influence legislation in the proper direction. We certainly need such an institution merely for the calibration of instruments, not considering the idea of a research department. I don't know whether we ought to say that we can find in America the man who would make an institution in this country as renowned as is the Reichsanstalt in Germany. Think of the two men who have been at the head of that institution. Helmholtz was a prominent physsician, a foremost physiologist, a superior physicist, in fact, a broad and cultured scientist. He was a man who would conquer anything, and who was especially fitted for this kind of a position. Kohlrausch—I had the pleasure of being his assistant for two years—is a man of the most wonderful scientific imagination, and in addition to that fact he criticises himself unsparingly. He was the most prominent advocate and supporter of the laboratory system of instruction in its early days. I think his little *Leitfaden der Praktischen Physik* was the first book on laboratory physics. Now two such men could not have failed to have brought renown to the institution with which they were connected. I do not question but that we might find somebody who would do the same for us, if he were not hindered because of our methods of legislation and government.

That we have a need for some bureau of unquestioned authority has come to my attention in some work which I have done for two different companies along almost the same lines. The products which they turned out did not differ from each other to any great extent, not much over a tenth of a per cent., but the products of the one company differed by about two per cent. from the products of the other company. Their supposed standards, to which they referred, were not multiples or submultiples of the same unit.

DR. CHARLES AVERY DOREMUS:—If an associate may be allowed to speak on this question, I happened the other day to pick up some of Sir Humphrey Davy's works, and in an address before the Royal Institution in London he urged that funds be appropriated for original research. He claimed that the nation which owed its progress to scientific endeavor would never have its citizens suffer the humiliation of slavery; that "science for its progression requires patronage, but it must be a patronage bestowed, a patronage received with dignity." I have tried to quote some of his words. Surely nothing could be more dignified for the promotion of scientific research than that the nation should be the patron, and nothing could subserve the purposes of what has been contemplated by this paper better than to have the Government of the United States not imitate necessarily the Reichsansalt or bureaus of other Governments, but establish something of its own on lines peculiarly original, though duplicating perhaps some work of others. I would like to say as a chemist that considerable advance has been made for the standardization of chemical instruments. We have been at work through committees and the like for some years past, and we are now having numbers of vessels standardized at Washington by the Government, a small fee being paid for the same, and I am under the impression that this bill of Secretary Gage's contemplates the union of all such calibration methods. When we consider how largely our chemical industries have developed in the last few years, how enormously they are going to develop in the next few, how absolutely essential it is to have accurate instruments for measuring solutions, for verifying weights, for making all sorts of computations, it is quite evident that there is a field in that direction which is quite as important as the electrical field. I am under the impression that Congress has already been memorialized from the chemical side of the scientific professions, and if the different institutes and different scientific societies of this country were to act in unison, I am very certain that very fruitful results would issue, perhaps in the next session of Congress.

Mr. Townsend Wolcott:—I want first to speak about those lamps that the Navy Department sent over. As I understand, Mr. President, you say that the amyl-acetate lamp is exceedingly accurate; but is it easy to use in calibrating electric incandescent lamps?

The President:—It is easier to use than any other standard.

Mr. Wolcott:—The Navy Department had some lamps, I think ten primary standards and twenty secondaries, and a lot more tertiary standards. At first they had intended to have them all standardized by comparison with the amyl-acetate lamp, and then after they got them they were to use the primary standards only to standardize the secondary, and the secondary only to standardize the tertiary. The tertiary standard was the one they would really use in daily work, so as to preserve their primary standards as long as possible. But the Reichsanstalt said that they could not do them that way; at all events, it would be entirely too much work; they would compare one lamp with the amyl-acetate standard and compare all the others with that. It seemed to indicate that they found it a great deal more work to compare an incandescent lamp with the amyl-acetate lamp, than to compare one incandescent lamp with another. The amyl-acetate lamp and the incandescent lamp are not exactly the same color. With two incandescent lamps of exactly the same color—that is, the same temperature—you can set the carriage of the photometer, if it be Lummer-Brodhun type, to a single millimeter every time, set it three or four times, and get the same result; whereas, if there is the slightest difference in the color you cannot do that.

Then in regard to standardizing instruments in this country, the Signal Corps here in New York had a Wheatsone bridge, which was rather old, and they wanted it standardized, and sent it to the Coast Survey. It was standardized. That is, each coil was measured, but they had no facilities for adjusting the coils. It is a little better to know when a coil is out, to know just what it is than not to know at all, but it is not nearly so good as having it adjusted so that it is right. It is somewhat humiliating that we have in this country no government institution for adjusting instruments accurately, and the advantage that some such institution as the Reichsanstalt would confer if we had one here is manifest.

Dr. Louis Bell:—As Chairman of the National Electric Light Association Committee on standardizing electric lamps, I would say that the question regarding standard of light is one of direct interest. The committee has definitely accepted the amyl-acetate standard as the ultimate standard to which light should be compared; but it is a fact that owing to the slightly reddish cast of the amyl-acetate lamp, comparisons are by no means easy, and I am not at all surprised that the Reichsanstalt preferred to compare one or a few lamps rather than standardize a large number. It is, however, a wonderfully satisfactory standard to use aside from the question of the slight difference in color. The difficulty which our committee has found is not in settling upon methods or anything of that sort, but agreeing on any one systematic way of rating incandescent lamps, which will not cause a cat and dog row among the lamp manufacturers, who, for the most part, I am earnestly persuaded, are intent on turning out a good product, but are a little bit cautious about admitting any particular method of rating, which might at the present time or some future time have an unfavorable influence on the rating of some lamps. I think, however, that in the last year or two, manufacturers have been coming to realize more and more the meaning of a definite standard, and I feel sure that that difficulty is going to vanish. The committee is now pegging away at the problem, making arrangements to produce some primary standard lamps and supply them, but the difficulty which has been met so far has been very largely commercial, it being very hard to settle upon a rating of lamps, quite aside from the scientific problems involved in standardizing, which will not be a source of constant rows in the case of those who make and also those who use lamps. I think the question is settling itself very satisfactorily, and I have no doubt that by next year at the coming meeting of the National Electric Light Association the committee will be able to bring in a final report, and will also able to furnish carefully standardized incandescent lamps to all who desire them.

THE PRESIDENT:—In reply to a question which Mr. Wolcott brought up, I would say that the Reichsanstalt uses the amyl-acetate lamp only as a primary standard, for occasionally standardizing incandescent lamp secondary standards. When they make measurements of electric lamps, they always use these secondary standard incandescent lamps, and bring the voltage to the proper amount. The incandescent lamps are used far below their rated candle power, that is, at a much lower voltage than the normal. In that way they get a light of about the same color as that of the amyl-acetate lamps; the comparison then becomes easier and more accurate, and the standard lamps last longer. If I remember correctly, one of their standard lamps used in this way, has run for ten thousand hours, and is still of exactly the same candle power it was in the beginning.

CAPTAIN SAMUEL REBER:—I know that we all agree upon the establishment of a Standardizing Bureau in this country. The question which arises is: what action shall the INSTITUTE take to further the establishment of this Bureau? I know from the results of correspondence and conversation with officials of the Coast and Geodetic Survey in Washington that a bill, drafted by them, was sent by Secretary Gage to both the Senate and House of Representatives, and was introduced as House Bill No. 11350, on May 5, 1900, and as Senate Bill No. 4680, on May 14, 1900. The copy I have shows that the measure is very complete and amply covers the ground.

THE SECRETARY:—I have a copy of it at the office, and I was looking it over to-day. In addition to the bill, it goes into details as to the staff and the salaries and number of employees, and also in addition to that letters from prominent men in various lines throughout the country, making quite a complete document that was printed by the governmont.

CAPTAIN REBER:—After an extended hearing before the Committee on Coinage, Weights and Measures of the House, the bill was favorably reported, but owing to the press of business at the close of the session it failed to pass. I would like to ask if the INSTITUTE cannot take some action in the way of urging its passage. If a committee were placed in charge of the matter they could decide whether it is advisable to take it up on the lines of the bill, and if so, to then act on the matter.

THE SECRETARY:—The Council has already appointed a committee, and one or more members of it have appeared before the Congressional Committee at Washington in advocating this measure. At a meeting of the Executive Committee to-day the Chairman was called upon to make a report as to what further steps were necessary, the idea of the Executive Committee being that it would perhaps be advantageous to enlarge the committee by putting on a member in each State, as far as we could, or something of that kind, in order to carry out this line of work in bringing the attention of Congressmen and Senators in various parts of the country to the importance of this measure.

DR. DOREMUS:—I would say that the American Chemical Society which is a national society, has taken this up, and that the different agricultural stations throughout the United States are highly interested in the matter, and that the Department of Agriculture, especially the chemical division of the Department of Agriculture in Washington, is extremely interested, and has pushed the matter quite some, so that there is a very good chance for proper influence to be brought to bear to show the necessity and the needs of the manufacturing community, and the scientific community, particularly, to get this bill properly presented to Congress, and I believe that our national societies would gladly cooperate.

MR. E. H. MULLIN:—I was speaking the other day to a Congressman, who is now serving his sixth term in Washington, about this very bill, and he told me that if deputations were to go down in support of the bill, it would be of the best service in January next. He also told me that the most practical means of urging this bill upon the various Congressmen was for each member of each institution such as this, to write to his local Congressman from his own home and bring that pressure to bear, and he also said a third thing, and that was that the Washington officials should keep as much in the background as possible.

He is in favor of the bill himself, and will do his utmost to help to pass it.

Mr. Frederick V. Henshaw:—It seems to me that there are some important factors in this question which possibly have not been brought up. I came in a little late, perhaps they were mentioned before. I do not wish in any way to belittle the effect of societies and scientific institutions on legislation, but I think they need a little more backing if anything is going to be accomplished satisfactorily. A good many societies have been working on the patent office question for a good many years, and I do not see that they have gotten any very satisfactory fruit. Now, if this Government Bureau is to be of great advantage to the manufacturers of this country, as I think everybody concedes it would be, there is one factor. If you can get the rich corporations and the men of influence interested in manufactures to use their weight, that would be one thing. Then there are the army and navy. I notice in Prof. Carhart's paper he speaks of a communication from the United States Navy in regard to standardizing. The navy is working towards various standards both in mechanical and electrical engineering features, and the Army of course is doing the same thing to a somewhat less extent. Now, if a bureau could be established which could fix the standards for both the army and navy, it would simplify a great many things, and be of great benefit, and if the engineer officers of those two Government departments were strongly in favor of this I think it would be a very great factor in the establishment of such a bureau.

Captain S. Reber:—In answer to the suggestion just made, I may say that as far as the army and navy are concerned, I know they are both very much interested in the establishment of this bureau.

As a result of practical experience I agree with the statement that a resolution of a society does have the weight with Congress that it perhaps should. Congressmen, as a rule, do not take interest in the advancement of pure science or its application, but are much more responsive to personal pressure than to a series of formal resolutions from a technical society.

Mr. Mullin:—How would it do to have a circular letter sent to all the members of our Institute asking each member of the Institute to write a letter to his local Congressman in support of this measure? As I have heard about the measure, it is this way: It so nearly passed at the last session that it would pass with proper pressure in the short session, but it is one of those measures that if it goes over for a year or so becomes one of the regular annuals in the House that they always think of passing, and never pass. You have an excellent opportunity now, and perhaps as good an opportunity will never occur again.

The President:—This matter is in the hands of a Committee of the Institute; it came up to-day at the Council meeting, and it was decided to ask the Chairman of that Committee to report on what the Committee considered to be the best action for the INSTITUTE to take. Any members having any suggestions to make, would do well to communicate with this Committee of the INSTITUTE.

DR. FRANCIS B. CROCKER:—I visited the Reichsanstalt some time ago, but the matter is so forcibly stated in Professor Carhart's paper, that there is very little to add in the way of an argument, and apparently the matter of bringing it favorably to the attention of Congress is in the hands of a committee. It seems to me there is not very much to be done. It appears to be the unanimous opinion of all our members here, and I think of the absent members, that it is a very desirable thing to bring about. In fact, it is so clearly true, that it is hardly necessary to add any testimony. The question has been up for a long time. I remember when Dr. Mendenhall was Superintendent of the Coast Survey he made a beginning in this movement to establish an electrical bureau or electrical department in the Bureau of Weights and Measures. I might add that this Government is not so very deep in barbarism as some of the speakers would imply. The Bureau of Weights and Measures has standards that are as good as those possessed by any country, and it is perfectly able to verify or to compare those standards with others that may be submitted to it. The Coast Survey of this country is a scientific department which has done most admirable work. In the measurement of base lines, for example, it is unexcelled, and its pendulum determinations of gravity are fully equal to those done anywhere else. So we already have started and started many years ago in this direction. It only remains to give additional assistance and money, to carry the work into the electrical field especially, and the chemical as well, in order to have a scientific department in Washington which would be very creditable. I think myself that the influence of the various national bodies, if brought to bear directly—if the committee report contained the official endorsement of the various bodies—I am sure that it would have weight. A Congressman is also affected by personal influence; but in a matter of this kind it is largely a question of whether it is a desirable thing to do or not. It is not a personal matter; it cannot be made a personal matter, and it seems to me that this body and other bodies should put themselves squarely on record, and that record should be, if possible, placed before the Congressional Committee, and attached to the bill in some form, and I am very sure it would have some weight. Of course adding to that the personal influence of the various members and bringing pressure to bear on the local Congressman would still further influence the result. But it seems to me the thing is so very desirable, that it is only necessary to bring it up to have it pass.

The President :—If there is no further discussion, I will show briefly how the spherical candle power of incandescent lamps is measured at the Reichsanstalt. It is quite ingenious, but it may not be new. The lamp is placed in a horizontal position, in the axis of the photometer, and is stationary. Around the lamp are revolved two flat mirrors making a certain angle with the axis. The direct light is cut off by a black screen. The light which is measured is that which falls on the mirrors, and is reflected into the photometer. The advantage of course is that you do not revolve the lamp, and the filament is therefore always in exactly the proper position. In this country I believe the lamp is generally revolved. With high voltage lamps the filaments are rather long, and if you revolve such a lamp rapidly enough to get no flicker in the photometer, the filament is apt to bend over to one side, due to centrifugal force.

[Adjourned.]

[Communication Received after Adjournment.]

Dr. A. E. Kennelly :—There can be no doubt as to the great importance of the work which the Charlottenburg Institution has carried on through the last decade. The researches which have been carried on there have been of great value, not only to Germany, but also to the whole scientific world. The work of such an institution fosters scientific inquiry, indirectly promotes justice and morality, and directly aids ingeneering. There can be no doubt that such an institution in America would be a matter of national importance and advantage. Considering the enormous value to modern civilization of scientific knowledge in general and of engineering, or technical knowledge in particular, it is difficult to imagine a more useful type of institution than the Reichsanstalt. No public gift could be of greater public advantage than such an institution, unless, perhaps, a hospital or a university.

The founding and endowing of such an institution by Government would naturally depend for its economic justification upon the more purely utilitarian aspect of such a bureau as a national industrial asset. It would seem that, from this standpoint also, the expense incurred in such endowment would be justifiable. In the first place, one of the duties of such an establishment would no doubt be the care and comparison of all physical standards, such as those of length and mass, and which already require and receive appropriation from the national coffers. The institution would be, therefore, but a natural extension of a bureau already existing at Washington. In the second place, the institution would, if properly administered, be reimbursed of a large porportion of its expenses in the fees which it would receive for the comparison and standardization of chemical and physical apparatus for industrial purposes. The saving to the community in expenses which are now rendered necessary by the want of a national standardizing bureau, would more than pay for the deficit, on any reasonable scale of expenditure. All this, however, naturally rests upon the assumption that such an institution was conducted and controlled on civil-service principles, as distinguished from political principles. If the bureau became a mere political office, a splendid opportunity for the fostering of knowledge, skill, accuracy, engineering and trade would be more than wasted.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, October 24th, 1900.

The 147th Meeting was held this date at 12 West 31st Street, and was called to order by President Hering at 8.20 P.M.

THE SECRETARY:—At the meeting of the Council this afternoon it was voted to hold the next General Meeting at Buffalo, and although the exact date was not determined upon it will probably be about the middle of August. At the same time the question of inviting foreign societies was considered, in return for the courtesies extended to the INSTITUTE during the present season, and a committee of five was appointed to formulate and present to the Council a programme for the meeting and various entertainments next summer. The committee consists of Mr. C. O. Mailloux, Chairman, Mr. Sever, Dr. Sheldon, Mr. Lieb and the Secretary.

At the same meeting this afternoon the following Associate Members were elected:

AYLMER-SMALL, C. SIDNEY	Assistant, Electrical Engineering Department, Columbia University, New York; residence, 52 Franklin Avenue, Passaic, N. J.	F. B. Crocker. Geo. F. Sever. F. Townsend.
BURDICK, IRVING EDWARD	Treasurer and Engineer, Naval Electric Co., 95 Liberty St.; residence, 115 West 49th St., New York.	Chas. W. Price. Ralph W. Pope. F. E. Kinsman.
FOWLER, GEO. W.	Electrical Expert, The C. & C. Electric Co., Westfield, N. J.	John L. Hall. Chas. Hewitt. Theo. Spencer.
GLASS, LOUIS	Assistant General Manager, Pacific Telegraph and Telephone Co., Telephone Bldg., San Francisco, Cal.	J. A. Lighthipe. H. A. Russell. C. W. Waller.
HASSLER, CHAS. T. F.	Electrical Engineer, "Union" Co., Riga, Russia.	C. P. Steinmetz. Ernst J. Berg. Eskil Berg.

Heitmann, Edward Jr.	Stanley Electric M'f'g. Co., Pittsfield, Mass.	C. C. Chesney. John F. Kelly. F. A. C. Perrine.
Parshall, August	Commercial Engineer, Supply Department General Electric Co., 88 Cannon St., London, E. C.	H. F. Parshall. J. R. Lovejoy. H. M. Hobart.
Rossi, Harold J.	Electrician, Puebla, Mexico.	C. F. Beames. P. H. Evans. C. W. Evans.
Rustin, Henry	Chief of the Mechanical Bureau, The Pan-American Exposition, Buffalo, N. Y.	Geo. F. Sever. Luther Stieringer. T. C. Martin.
Smith, Samuel James	Salesman and Installing Engineer, Crocker-Wheeler Co., Y. M. C. A. Building, Charlotte, N. C.	Fred D. Sampson. Gano S. Dunn. F. V. Henshaw.
Stitzer, Arthur Bowers	Draughtsman, Union Traction Co.; residence, 1909 North Camac St., Philadelphia, Pa.	Chas. Hewitt. Minford Levis. R. H. Klauder.
Thomas, Percy Holbrook	Electrical Engineering Department, Westinghouse E. & M. Company, Pittsburg, Pa.	Chas. F. Scott. L. B. Stillwell. A. J. Wurts.
Thompson, Warren Ray	Assistant in Electrical Engineering Department, J. G. White & Company, 29 Broadway, New York	R. D. Mershon. H. A. Lardner. J. J. Kennedy.
Walmsley, Walter Newbold	Superintendent of Construction, American Engineering Co., Pomeroy, O.	Chas. Hewitt. C. A. Bragg. Minford Levis.
Webb, Howard Scott	Professor of Electrical Engineering, University of Maine, Orono, Maine.	D. C. Jackson. S. B. Fortenbaugh. B. S. Lanphear.
Wheildon, Louis B.	Contractor and Expert, 1010 Exchange Building, Boston, Mass.	H. C. Spaulding. C. K. Stearns. Ralph W. Pope.
Whitehead, John B., Jr.	Associate in Applied Electricity, Johns Hopkins University, Baltimore, Md.	L. B. Stillwell. C. T. Hutchinson. Ralph W. Pope.
Wieselgreen, Carl Emil	Yonkoping, Sweden.	Ernst J. Berg. W. I. Slichter. C. P. Steinmetz.
Wolf, Lee H.	Contracting and Engineering, Honolulu, H. I.	Geo. P. Low. F. F. Barbour. A. E. Brooke-Ridley.

Total, 19.

Vice-President Lieb then took the chair, and the President read his Inaugural Address.

Inaugural address by the President at the 147th meeting of the American Institute of Electrical Engineers, New York, October 24th, 1900.

THE PARIS EXPOSITION OF 1900.

BY CARL HERING.

A large international exhibition, like the one about to close, may be judged from two standpoints. For commercial reasons a necessary feature is its general attractiveness, that is, its beauty, architecturally as well as in the arrangement of the grounds and in the decorations, its proper combination of instruction and entertainment, and its purely entertaining features. On the other hand such an exhibition should be a representation of what is called the state of the art in the various industries, and to a certain extent at least, show the relative importance of competing industries.

From the first of these standpoints this exhibition may be said to have been a great success. It certainly was very beautiful and attractive, and in this respect it was typically French, for to the Frenchman such an exhibition would be a failure if it were not beautiful. While there were undoubtedly a few architectural features that might be criticized unfavorably, yet in general the buildings and arrangement of the grounds left little to be desired, although the absence of straight lines in the architectural decorations of the main buildings might not meet with the approval of every American, for in this respect they differed typically from those in the Chicago exhibition. The arrangements and decorations of the characteristically unsightly interiors of long exhibition buildings, were also very tasteful and effective, although the avoidance of a regular system of aisles made a systematic study of the exhibition an almost hopeless task. In some of the attractions, such as the Optical Palace, the underground mines, etc., instruction and entertainment were combined, but as a rule the too numerous "side shows" were for amusement only, and were typically French.

From the other standpoint, that of showing the state of the arts, the exhibition may have been, and undoubtedly was, a success in many departments, but that claim can hardly be made for the electrical industry. For France, Germany, Switzerland, and a number of the other continental countries, the electrical exhibits doubtless represented the true state of the art and the best general practice as far as these countries were concerned; but the absence of a proper representation from the United States proportionate to the enormous development, made the exhibition an incomplete representation of the present state of this important industry. Any one judging its development in the respective countries by their exhibits, would have obtained a very wrong impression of its progress in the United States, or of the general practice here. We sent over a few excellent electrical exhibits, and they were greatly admired, but there was general disappointment that a country in which the electrical industry is known to be so largely developed, was so inadequately represented. This is all the more unfortunate at the present time when our export trade of manufactured articles is growing so rapidly, and when our electrical practice, in certain directions at least, is thought so well of by foreigners that many of them come over here to study it.

The fact that several of our largest manufacturers have ceded their rights in foreign countries to local companies and therefore claimed to have no interests there, may explain in part the absence of some of the important American electrical exhibits. But unfortunately these local companies do not always follow our practice, and do not manufacture the goods on the same scale and in the same way, so that their exhibits were not as a rule representative of our products.

England also was very inadequately represented in the electrical classes. The English claimed that they were tired of exhibitions, but another reason is no doubt the unfortunate political relation with France. England's exhibits in other groups also seemed to fail to represent the proper magnitude of the respective industries in that country.

Of all of those foreign to France, Germany, its former bitter enemy, had by far the finest exhibits in most of the groups, including the electrical. Another feature of interest politically, is that Hungary had in many respects better exhibits than its stepmother country, Austria, and was represented as an independent nation; it bids fair to become one of the greater industrial countries of the east.

The question is frequently asked how the Paris exposition compared with the one in Chicago in 1893. As both were very large and creditable, a comparison becomes difficult and in order to give an opinion of any value one ought to have studied both equally thoroughly, and under equally favorable conditions. It is also largely a matter of individual taste, and depends on the nationality of the one giving it, as also on the extent of his knowledge of French. The area of the Paris exhibition was 336 acres, which together with the annex made it about half as large in area as the fair in Chicago which had about 1000 acres. The average number of paid admissions seems to have been about double in Paris, due to the fact that it was so managed financially that the average admission was about seven to ten cents as compared with somewhat less than fifty cents at Chicago. Americans seem to have obtained their unfavorable views from antagonistic English papers.

It is thought safe to say that the Paris exhibition, taken as a whole, was more generally beautiful in details, but that it contained no single group as magnificent as the famous Court of Honor, nor were the illumination effects as fine as at Chicago, where they were electrical, while in Paris gas was largely used, the whole of the largest open area, the Champ de Mars, being a brilliant mass of incandescent gas lamps. Neither had as finely illuminated fountains as the exhibition of 1889 in Paris, although the background to the poorly illuminated fountains in the present exhibition, forming the famous Chateau d' Eau or Water Castle, was very beautiful and attractive.

The means of getting to and from the exhibition were very poor, as Paris has unquestionably the worst managed tramway and 'bus system of any large city in the world; its cab system, the best and cheapest of any large city except perhaps London, was of course entirely inadequate and too expensive, for the exhibition traffic. The exhibition however had the great advantage of being practically in the city itself, and in one which is admitted to be the most beautiful in the world, offering many attractions to visitors, and containing treasures which make it in itself an exhibition worth going to see. The Paris exhibition was decidedly more truly international than the one in Chicago, and the social intercourse of those officially connected with it was for this as well as for other reasons, including the generous hospitality of the French, more interesting.

The electrical exhibit was greater in Chicago, where it filled a large separate building, while in Paris it was confined to a moderately small part of one of the buildings.

Among the classes of exhibits of well-developed industries, there were three in particular which may be mentioned here specifically, as each marks a distinct and important direction of development, and was exhibited for the first time very prominently at a large international exhibition. They are the automobile, the incandescent gas lamp, (known here as the Welsbach,) and the three-phase generators, motors and systems. The automobile exhibit was very large, but unfortunately for the electrical industry, it seems that the gasoline vehicle is gaining very fast in the race with the electric. In Paris where automobiles are being used quite extensively, the quiet but heavy electric vehicle is seen only occasionally, while the light but noisy and malodorous one using gasoline, is heard and smelt very frequently. The incandescent gas lamp was used in large numbers on the Champ de Mars, the only large open area in the exhibition, where arc lights would otherwise have been installed. Even the friends of the electric light must admit that the illumination produced by it was very effective, brilliant and white without being dazzling. This lamp is getting to be a very serious competitor to the electric light, and some of the European central stations, particularly in the home of its birth, Austria-Hungary, are having serious difficulty in competing with it. The third of these prominent classes of exhibits, the three-phase machinery, will be referred to below.

Another feature of indirect interest to the electricians is that most of the acetylene illumination was relegated by the authorities to two small strips of land unoccupied by any buildings, along the banks of the river, which seems to indicate that acetylene illumination is limited to a narrow field of its own.

Much else might be said about the exhibition in general, but we as electrical engineers, are more interested in the electrical exhibits. As was already mentioned above, these were representative of the state of the art only as far as the continental countries were concerned, as those from the United States and England were very deficient in scope. It was also stated above that it was less of an electrical exhibition than the one at Chicago. There were moreover no quite novel, epoch-making electrical inventions shown, although a few quite interesting ones that were already known to readers of the electrical journals, were exhibited there for the first time. Detailed descriptions of all the important apparatus have doubtless been or will be given, in the electrical journals where they more properly belong and where they can be read at one's leisure, and therefore no attempt will be made here to give such descriptions, even if time permitted, the intention being merely to mention some of the chief features and to make some general observations.

One of the striking features was the great prominence of three-phase generators, and their size. One obtains the impression that the three-phase current has triumphed over all the others, including the continuous current, when large amounts of power are concerned, and that it would be poor practice now to install large units of any but the three-phase system unless one is forced to use another. There was shown a decided tendency toward the use of large units, and quite a number were exhibited having outputs of about 1,000 kilowatts and over. The greater number were for three-phase currents and all formed the fly-wheel of their direct-connected slow-speed engines, while all of the few large continuous current machines exhibited, had to have a separate fly-wheel. That the field is made the revolving part seems to be almost universal practice, as also the distributed winding on the armature. Single and two-phase alternators and large continuous current machines were the exception.

Two very ingenious attempts were shown to compound large, three-phase generators, without commutating the main current, one by Hutin and Leblanc and the other by Boucherot. Both excite their direct current and mechanically coupled exciter, by means of the three-phase alternating current, the exciter therefore having a revolving field but fixed brushes; in both, the excitation of the exciter is dependent on the voltage of the alternator and on the main current, in the former by means of a shunt and series field magnet coil, and in the latter by means of a transformer combining the effects of both. To obtain direct current from such an exciter the connections between the commutator and the coils in the former are reversed according to a certain law, while in the latter the armature has several windings differing in their number of turns according to a sine law. Both claim to keep the voltage of the generator constant for different currents and load factors. It will be noticed that there is no commutation except that of the small exciting current in the direct current exciter. Whether they are better or worse than the commutating systems used here, practice alone can decide. While they are interesting studies, it does not yet seem to be proved that for large units at least, a cheaper attendant than these would require, with his hand on the rheostat and his eyes on the voltmeter, is not a more practical solution.

The amortisseur of Hutin and Leblanc, consisting of a short-circuited cage through the poles of the magnets, for facilitating parallel running, seems to be meeting with some favor and is being commented upon very favorably.

The largest generator exhibited was a 72-pole, 3,000 K. W. three-phase machine, of the Allgemeine Elektricitaets Gesellschaft of Berlin. Its speed was 83, frequency 100, voltage 6,000, weight about 160 tons, and diameter of revolving field about 24 ft. As many as 21 of these are under construction. It was claimed to be the largest in the world, but this is an error, as generators of 4,000 K. W. and over are in use in this country at even slower speeds. Several others above 1,000 K. W. were shown, the slowest speed being 72, of the 2700 K. W. mixed single and three-phase current Helios machine.

The direct generated voltages of the three-phase machines was from 2,000 to 6,000 volts; there was one exhibit of a comparatively small generator for 30,000 volts, but as long as good transformers can be bought, such excessively high voltage machines will probably be used only for exhibitions and laboratories.

There were a number of inductor alternators exhibited, which indicates that they are meeting with some favor.

Connecting lamp circuits to three-phase generators does not seem to be considered a sufficiently serious matter to overbalance the advantages of that system. The method used by the General Electric Co. of Berlin (that is, the Allgemeine Elektricitaets Gesellschaft, which even in Germany is generally abbreviated to A. E. G.) is simply to distribute the lights as evenly as possible over the three branches. All three mains are run into the buildings of even small consumers, although only two may be used, the third being available for changing over a batch of lamps, if necessary, for balancing. The voltage can thus be regulated only for all three branches together, and not for each separately; but this is not considered a serious disadvantage. The Oerlikon Co. on the other hand, connects lamp circuits between the ends of only two of the three branches of a star-connected winding, the third branch being then idle; this enables the voltage of that single-phase alternating current circuit to be regulated at the machine. By overloading these two circuits 15%, the capacity of the generator is about the same as for motor circuits with a power factor of 0.8. The units in a station can then be alike, and it does not interfere with paralleling, or running motors and lights from the same machine if necessary. Another method used in Switzerland but only with two-phase generators, is to construct a sort of double machine, the two halves of which may be mechanically displaced relatively to each other to generate two-phase currents for power purposes, or they may be connected in line with each other to generate single-phase currents for lighting.

The high voltage, direct current series system for power transmission and very limited distribution, made another and probably unsuccessful appeal for recognition, in the form of an exhibit by its indefatigable champion, Mr. Thury.

The large engines exhibited were as a rule slow speed, which is the prevailing practice on the continent. The very high-speed steam turbines are also meeting with favor.

Among the various types of motors, the most interesting was the three-phase induction or Tesla type, which seems now to have demonstrated its superiority over all the others except perhaps the continuous current motor, upon whose field it is however encroaching very decidedly, with the present prospect of becoming its equal in importance. The largest company in Germany and perhaps in the world, estimates that its sale of three-phase induction motors will before long exceed that of its continuous current motors. Its very large factory, including even the rolling mill, is equipped with these induction motors mostly direct connected. There is a single textile factory in Switzerland in which 500 of these motors are used for direct driving. The induction motors, almost exclusively of the three-phase and not two-phase type, are being introduced very largely now, especially in Germany and Switzerland.

A nearly uniform type seems to have been adopted by most of the makers. In this, the primary circuit is the stationary one, and is distributed over the surface like a drum winding, as distinguished from the coils used in the earlier forms of Tesla.

It is this distributed winding which is the chief improvement that has made them such a success; it seems to have been first introduced by Dobrowolsky in Berlin. The larger ones are almost always started with a resistance in the secondary external to the motor; in some cases a short-circuiting device is provided on the rotor for use after starting, so that the brushes may be raised while running, to prevent wear. It will be noticed that in some respects this nearly universal practice abroad differs from that in this country where even very large motors up to 800 H. P. if not more, are made without any brushes, being started with a transformed current at lower voltage: others are made with the starting resistances on the rotor itself, which also dispenses with brushes.

Among the few other devices exhibited for starting such motors, the object of all of which is the avoidance of slide rings, may be mentioned the ingenious one of Fischer-Hinnen, who uses an inductive resistance of very low ohmic resistance, in parallel with a non-inductive one of high ohmic resistance; together they act like a high ohmic resistance when the motor starts, owing to the high frequency of the secondary currents, and diminish automatically as the motor increases in speed, because the frequency of the secondary then diminishes; they are permanently connected to the rotor. In the Deri motor the number of poles is changed by a switch in the primary, and the resistances are permanently connected between points of the secondary which have a difference of potential for one number of poles, but are of the same potential for a different number of poles; they are therefore either in or out of circuit and admit of no gradation, which is a disadvantage. Boucherot uses practically a double motor, the field of one of which, may be mechanically turned through a certain angle for starting; the two secondaries are permanently short-circuited in series with each other, but have resistances connected between the coils through which the secondary current is forced to pass when one of the fields is displaced, but only then; it seems like a rather complicated device as compared with the simpler slide rings which it replaces.

For the A. E. G. induction motors, Dobrowolsky claims that they will stand a 200% overload, have a power factor of over 0.9 and still give the normal output for two thirds the normal voltage.

Induction motors are built on the continent for high voltages up to 6,000 and I believe even 10,000, thus saving the transformers for all but higher voltages than these.

As to single-phase induction or non-synchronous motors, it looked as though most of their makers thought it best not to exhibit them, or to evade questions asked about them. Among the exceptions may be mentioned the Brown and the Oerlikon motors both of which start with an auxiliary winding. Brown, who constructs them up to 100 H. P., states that they start with ½ to ⅓ full load torque at about normal full load current. He has even made them for starting with full load torque at about double normal current. The air gaps are very small, from 1 to 1½ m. m. A cheap liquid condenser made of iron plates in soda solution, is used for producing the artificial starting phase. The Oerlikon motors are claimed to start with ½ normal torque requiring 80% normal current, and to stand an overload of 50%. An impedance coil is used for starting.

A very interesting installation of single-phase motors, and quite a unique one, exists in Frankfort o. M., Germany, where about 500 such motors, mostly by Brown, are connected to the large single-phase alternating current plant, the motor load of which has leveled the load curve very decidedly. They vary in size up to 100 H. P. and are used even for elevator work. They appear to be satisfactory to the users, even though they must always be started unloaded. This is probably the largest motor plant of its kind and shows what can be done even with single-phase motors.

One of the applications of three-phase induction motors which is of special interest, and which seems to have a promising future, is to traction. This three-phase traction system, which is scarcely known in this country, is in regular and apparently very successful use on a number of lines in Switzerland, where it is being introduced by such well known constructors as Brown, Boveri & Co., and the Oerlikon Co. A few of these roads were visited by the writer and as far as could be learned they were running very satisfactorily. The double trolley wire, which is essential, and which has often been urged as being such a serious objection, does not seem to give any trouble at all; each locomotive or car had even two contacts with each wire. Many of the alleged objections are overcome by the use of the contact bar instead of the trolley wheel, which completely avoids any jumping off of the pole, and greatly simplifies the overhead wiring at the switches, which is in fact not complicated at all. The motors are started with resistances in the secondary as usual. There is no complicated controller, as the two motors are always in parallel. The trains start well and without difficulty, and it seems, without any very abnormal current. The chief objection to the system seems to be that the running speed is always the same, in which respect it is like a cable road; it is therefore not possible to make up lost time except on a down hill coast, while on steep up grades there is a considerable demand for power as the speed is always the same maximum. No system of efficient speed regulation is used, presumably because none has been found to be satisfactory. This seems to be the real and serious objection to the use of the system in this country, where high speed seems to be an essential requirement. One of the freight locomotives was provided with a purely mechanical device for halving the normal speed, but no other information could be obtained than that it was then in the repair shop.

On that bold enterprise, the Jungfrau Bahn, which will ascend one of the highest snow peaks in Europe, a very ingenious and apparently novel device is used on one of the Oerlikon three-phase locomotives, in order to enable a train to descend to a habitable region even if connection with the power house is broken or if something should happen to the trolley wires or poles. Ordinarily in descending, the induction motors act as generators, sending their current back into the line, which therefore must be intact. The device referred to, consists of a small direct current generator driven by the descending locomotive, the current from which is led into one branch of the star or Y-connected primary and out at the other two ends in multiple; this excites the motor and it then generates alternating currents in the secondary which are dissipated in the resistances used for starting; it thus operates as an electric brake without being in contact with the line.

While three-phase traction in its present state would probably not be practicable here for cities, there seems to be a field for it on long distance interurban lines with few stops, as it is much cheaper. The estimates for the Jungfrau Bahn showed that the first cost would have been 50% greater if the continuous current had been used on the locomotives, as is done in this country.

Returning to the subject of alternating current generators and motors in general, there is a characteristic difference between

European practice and that in this country which seems worth mentioning. Here the coils are usually form-wound and then laid into open slots; there the wires are more generally threaded through completely closed holes as in the Oerlikon and Brown machines, or through holes of which the webs have been cut through with a very thin saw cut, as in the Dobrowolsky machines of the A. E. G. Mr. Brown gives the following reasons for his preference: lower magnetic resistance, smooth surface of core, seamless tube insulation, solid poles, ease in parallel running and avoidance of wedges, binding wire, etc.; his experience is that it takes as long to replace a form-wound coil as to thread in a new one in place. Dr. Behn-Eschenburg, the engineer of the Oerlikon company, gives his reasons as follows: The smoothness of the surfaces enables the air gap to be made as small as 0.001 of the diameter in induction motors, which is hardly possible with teeth; with a web over the hole of only 0.1 m. m. the coefficient of magnetic straying can be reduced to 0.04 and a maximum power factor as high as 0.92 can be obtained; the maximum torque will correspond with 3.5 times normal current, and the possible overload can be 2.5 times the normal; if the holes were changed into teeth, all else remaining the same, the magnetization current would be at least doubled, the straying coefficient reduced to about 0.03, and the best current for the resulting maximum power factor of 0.94 would then be more than doubled and the copper conductors therefore increased, or for the same load the power factor reduced to 0.91; the slotted armature would have to be made longer axially if it is to have the same current at no load as the one with holes; moreover, seamless insulation tubes of micanite can be used in the holes, which if 1 m. m. thick will be quite safe for 3,000 volts. However he quite impartially recognizes the favorable features of slots with form-wound coils and admits that they may outweigh the others if a factory is suitably equipped for such work; he believes that under certain circumstances the one, and under others the other, is the better.

Another interesting characteristic difference between American and continental practice, is that here synchronous converters combined with transformers are more generally used for transforming high voltage three-phase currents into low voltage direct currents, while on the continent dynamos driven by high voltage induction or synchronous motors are the rule. Although the favorable features of each are well understood, the reasons given by such a successful constructor as Brown for preferring motor-generators, may nevertheless be of interest here. He states that: they can be regulated with ease and precision; no transformers; both parts can be better designed without making concessions; no hunting; ease in starting; no depolarization possible; secondary voltage absolutely independent of the primary. He admits that the synchronous converter is cheaper and more efficient, but claims that the differences are but slight; he has obtained 90% combined efficiency for a 250 K. W. motor-generator set.

The difficulty of not being able to regulate the voltage of a synchronous converter, is overcome by Dobrowolsky in a very ingenious and apparently successful way. Instead of passing the continuous current through a booster, which would require an expensive machine, and generally with a very large commutator, he passes the alternating current through an alternating current booster on the same shaft; this is separately excited with a continuous current and therefore permits of regulation. The one shown to me would raise or lower the voltage 25% making a range of adjustment of 50%. It either drives or is driven by the converter. Although this overcomes one of the chief objections to synchronous converters, he has not changed his preference for motor-generators.

Another modification of interest used by this same engineer and others, is that six-phase instead of three-phase currents are led into the synchronous converter, the advantage being that its output is thereby increased, according to a French constructor about 45%. The attending disadvantage of six slide rings instead of three, is said to be more than balanced. The general use of three-core transformers, for three-phase currents instead of a single one for each phase, as is customary here, is another instance of a difference in practice.

It was of some interest to note the almost complete disappearance of the Gramme ring armature among generators and motors, and the use of multipolar fields for smaller sizes than formerly, especially with motors. The Dobrowolsky system, hardly known here, of supplying three wire circuits from a single generator, by connecting the neutral through induction coils and slide rings to two opposite parts of the armature winding, seems to be meeting with favor on the continent.

A criticism of American motors made by a prominent German manufacturer who has bought and tested many, was that an American horse-power was only three-quarters of a real horse-power.

In electric railroading there seemed to be comparatively little of special interest to Americans, besides the three-phase motor system and the contact bar, already referred to, both of which deserve more attention here than they are getting. The new Metropolitan underground electric road quite recently opened in Paris, is apparently an excellently constructed but wretchedly managed road. American management would diminish the total time of transit and increase the profits greatly. It is an improvement over the new underground road in London in that motor cars are used instead of locomotives, but being directly under the street instead of very deep, as in London, the excellent device of a descending and an ascending grade between stations, to aid acceleration and stopping, cannot be taken advantage of. Both of these roads use American electrical machinery.

The two new electrically operated extensions of several steam railroads into the central parts of Paris; the new and much needed electric railroad to Versailles; and the new conduit road in Paris, are all of interest. A surface contact line and one using accumulators, are also being tried in Paris. The Western Railroad, one of the largest steam railroads of France, is making very extensive preparations toward introducing electric traction on its lines by more improved methods than its Heilman locomotives. If our steam railroads were as enterprising, the replacing of steam by electric traction would progress more rapidly here. Through the kindness of Mr. Clerault, the chief engineer of this enterprising steam railroad, our INSTITUTE had the pleasure of accepting an invitation for a personally conducted visit to its enterprising plant. It has already in operation in part, a large three-phase power station near Paris, accompanied by extensive laboratories; has constructed an electrical extension of its steam lines toward the center of the city; is building the new electric line to Versailles over an excellently constructed and well graded private roadway, and has under construction a number of electric locomotives. Paris is therefore at last beginning to avail herself of the advantages of electricity for traction, and will unquestionably be very greatly benefited thereby. If with this modern traction force, a more modern and more American system of managing and operating the city tramways were introduced, the Parisians, the many visitors and the owners of the tramways, would all be the gainers.

In the exhibition itself may be mentioned the two miles of moving platform which differed from the one in Chicago in that the motors were stationary while the rails moved. The third rail electric railroad paralleling it but running in the opposite direction, was virtually an American exhibit and was managed more like American roads, making a refreshing contrast to the wretchedly managed tramways and omnibuses in the city. Both the platform and this railway were fed from two 800 H. P. induction motor-generator sets made in this country, the induction motor, started by its mate, being one of the largest ever made. The conduit road which was shown, was also virtually one of those developed in this country. A short section of the "suspended" railway was exhibited, but whether this struggle for recognition was successful seems questionable. Another curious departure shown in operation was the trolley automotor, a system of running electrically driven vehicles on ordinary roads, but taking current from an overhead trolley wire. The novel feature was that the small contact carriage running on the two wires, was geared electrically to the motors by means of a local three-phase current, so that it tended to travel slightly faster, thereby always leading and keeping the connecting cable taut. A field for it might exist where omnibuses are now used.

A number of large electric locomotives were exhibited, notably one from Berlin, showing that heavy electric traction is making progress. One weighing about 45 tons exhibited by the French steam railroad known as the P. L. M., was operated with accumulators carried on a tender, but the claims made for it by the attendant were so remarkable that a verification is desirable before they can be considered. Although it was dated 1896, I was told that it was "not yet" in constant use.

In electric lighting, one of the most interesting features was the debut of the Nernst lamp. After long and tedious labors on the part of the General Electric Co., of Berlin, the interesting laboratory experiment of Nernst, that a filament of a non-conductor like magnesia becomes a conductor after it is heated,—has been developed into a form of high efficiency incandescent lamp, which is now claimed to be ready for the market; but although several hundred were burning there daily it was not possible to buy one. It resembles the usual incandescent lamp except that the bulb is open; the filament is somewhat thicker and much shorter than that of a carbon lamp; the light is very much whiter and more brilliant. It can be lighted with a match, alcohol torch or automatically by a platinum wire preheater with a magnetic interrupter. Either alternating or continuous currents can be used but the filament must be exposed to the air. The lamps are made for 25, 50 and 100 C. P. at 220 volts, and therefore do not yet compete directly with the usual 16 C. P. lamp. The efficiency is said to be 1.5 watts per candle, or about twice as good as the present carbon lamp of the same voltage. The filament is said to be made of magnesia mixed with the rare earths like zircon, thorium, etc. The life is claimed to be very satisfactory, though no figures could be obtained, but the perishable parts, valued at only 25 per cent. of the probable cost of the lamp, can easily be replaced, the bulb being open.

The material of which the filament is made, has a rapidly falling temperature coefficient, much worse than carbon, which would make it extremely sensitive to changes in voltage. This is overcome by a very ingenious method to which the present success of the lamp is due; it consists in placing a very fine iron wire in series with the filament, the wire being so proportioned that it is heated by the normal current to that temperature (about 450 to 500 degrees C) at which it has a very rapidly rising temperature coefficient; the resulting characteristic of the two in series is therefore a rising one. This fine wire consumes about 10 per cent. of the voltage. The price of the lamp, it is thought, may be about 50 cents.

Among the novelties in arc lamps which attracted some attention during the few days it was on exhibition, was the Bremer lamp in which the carbons contain certain salts, like those of magnesia, together with fluor calcium, that deposits a white oxide on surrounding bodies which acts both as a Nernst conductor and a white reflector, the carbons being inclined like the letter V. A reliable German authority found the efficiency to be 0.13 watts per hemispherical candle power. The light is said to be steady and bright but soft.

The only enclosed arc lamps exhibited were from this country, directly or indirectly. These lamps, which are so largely adopted here, are scarcely known on the continent, and in France at least, it seems that they are not even wanted, on the ground that the light is too blue and unsteady, and the efficiency too low. As manual labor is much cheaper there than here, and arc lamps are not used nearly as much, the chief advantage of this lamp is not appreciated, at least not yet. The arc lights there are, as a rule, much steadier, and are almost universally connected to constant potential circuits, our series system being almost unknown. The general type of regulating mechanism which is in favor, is that in which the coil applies a brake to an escapement wheel which tends to revolve by the weight of the descending carbon; the regulation is therefore very sensitive and gradual. Cored carbons of a fine quality are moreover almost universally used. Generally only two lamps are in series across the usual 110-volt mains, but in some cases as many as three are connected with an increase in light efficiency; in such cases the lamps are of the differential type in which the regulating mechanism is actuated not only by a shunt coil but also by one in series.

The exhibits of electric chandeliers and like fixtures were mostly French, and were generally very tasteful, artistic and often very beautiful, although frequently marred by external wiring, as with many of them concealed wiring is impractical. The accessories, on the other hand, such as circuit breakers, small switches, lamp sockets, motor starting resistances, etc., were frequently quite bad or too complicated, from an American standpoint. There would seem to be quite a market abroad for the better classes of American goods of this kind. It is hard to understand why electrically started fires are not more frequent on the continent with such poor appliances of this kind that one finds in use there.

The relatively large number of exhibits of switchboard switches for breaking currents of very high voltage, indicates the rapid introduction of high tension currents. In many of them the well-known double horn is used for extinguishing the arc, which is an indication of the effectiveness of this simple device.

A novel departure in switchboards, especially for dangerously high voltage machines, consisted in placing all the switching apparatus belonging to one machine, on or under a post or pedestal near the machine itself, and so that the attendant faces the machine. The actual switches are under the floor where they are out of the way and easily accessible from a pit below, only the levers, hand wheels and instruments being on the pedestal; the attendant is thereby protected from all the possible danger. It is the standard practice of the Oerlikon Co.

The use of silver fuse wire in place of lead alloys, by a very large German company, on the ground of greater reliability and constancy, deserves mention. For the same fusing current the amount of metal volatilized is the least for silver.

The non-interchangeable fuses of Siemens and Halske were of some interest and seem to supply a need.

Among the cable exhibits there were three for underground work in which multiple cored cables were subjected to 25,000 and 30,000 volts alternating, the insulation in one of these being impregnated paper without any rubber.

A German maker of aluminium goods showed that this metal can be welded without solder or flux by simply heating it to a certain definite temperature at which it softens. The use of aluminium line wires makes this simple method of interest to electrical engineers.

The number of different types of meters exhibited was about equal to the number of their exhibitors, but the Thomson meter in nearly the same form as made in this country, is the one most frequently used; several hundred a day are claimed to be made by the French company which manufactures them. The field for a good, cheap and simple ampere-hour meter for small consumers of continuous current, is filled very satisfactorily in France by the O'Keenan meter, of which 11,000 are already installed. In principle it may be said to be like a d'Arsonval galvanometer or Weston instrument, in which however the coil is mounted so that it may revolve continuously, the number of its revolutions being registered. This coil or armature is a shunt to a very low resistance in the main circuit. It is extremely sensitive and the coil requires only 0.6 microwatt to start it; it will register as little as 5 watts in the lamp circuit or 1% of its range, has a straight line characteristic and is not appreciably affected by temperature changes. A somewhat similar one is about to be introduced in this country and there is no doubt a large field for it.

The well-known and ingenious Aron double pendulum meter was well exhibited in various forms, including one for three-phase currents. It is said to be used to some extent in Germany but would probably not find much favor in this country.

An interesting and promising modification in the Thomson type of watt-hour meter, shown in the German section, consisted in using a three coil armature like that in the original Thomson-Houston arc light machines; this enables the same magnetic force to be produced by a much smaller weight of the revolving part, with several attending advantages of importance.

Prepayment meters are meeting with some favor and there might also be a field for them in this country among small consumers.

In telegraphy the exhibit which seemed to attract most attention was the very ingenious printing telegraph system of Professor Henry A. Rowland, of Baltimore. The sender merely presses lettered keys like on a typewriter, and at the other end the message is received in print on a sheet of paper ready for delivery, without requiring any operator. An alternating current of constant frequency is passed over the single line and operates synchronous motors, by means of which the necessary synchronism at the two stations is obtained. The different characters are transmitted by the suppressing of various combinations of the half waves of the current. At the receiver end those waves are received in a large number of relays, various combinations of which operate a few electromagnets for printing the characters and moving the paper laterally and lengthwise. The typewheel revolves continuously and the paper directly beneath it, is struck from below at the exact moment when the desired letter is over the paper. Four messages are sent at the same time in one direction, the line being loaned to each operator in succession for short recurring periods. This is then also duplexed, making eight messages simultaneously over one wire, each, it is claimed, at a speed of 45 words per minute. It does not seem to be used commercially yet, and whether it will be equal to or better than the printing telegraph system which has been in satisfactory commercial use between New York and Chicago for some time, devised by one of our members, can be determined only by equally severe tests.

There were several exhibits of the wireless telegraph system, though none by Marconi's company. The modifications were only in details and did not include any way of making the system selective. It is now being introduced commercially and there are a number of installations in regular use.

The telegraphone was one of the very few entirely novel inventions of promising value exhibited. This extremely ingenious and very interesting invention of Poulsen, a Dane, has been so thoroughly described in the journals that a mere mention will suffice here. It may be said to be a magnetic phonograph in which a long hardened steel wire is passed rapidly near the magnet of a telephone receiver, the magnetic variations of which are thereby recorded on it in the form of permanent magnetism. By then passing this wire under small pieces of iron attached to a diaphragm, the same sounds are reproduced. I had the pleasure of hearing such a reproduction and can vouch for the statement that it is much clearer than from an ordinary phonograph as there is an entire absence of that objectionable scratching noise, there being no mechanical contact at all. Its suggested applications are numerous, including duplex and multiple telephony.

Those interested in the controversy between the vertical and the horizontal telephone switchboard, found a good opportunity to compare them, as each was exhibited by its most ardent defender, the vertical board being advocated by one of our large and prominent companies, and the horizontal by a similarly prominent German company which is introducing it in its country, notably in Berlin. The chief advantage claimed for the latter is that two operators sitting on opposite sides can use the same board and that therefore the length of board for the same number of subscribers is halved.

Electrochemistry was one of the electrical classes in which the most pronounced recent development was shown, although the exhibits were not sufficiently complete to show the true state of that art. This branch of electrical science has opened what promises to be one of the important fields in which there is an opportunity for great development. Products which not many years ago existed only as rare and expensive specimens, and some which were not even known, are now made electrically by the ton.

Electric furnaces were shown in operation. There was also a very fine exhibition of the extremely interesting collection of products obtained by Moissan in his classical researches. Judging from two other large exhibits, copper is successfully deposited directly in the form of mechanically strong tubes, simultaneously with the process of electrolytic refining. A single company in Germany refines electrically about 5,100 ounces of gold and 24,000 of silver a day.

A very large ozone apparatus was shown in operation, for sterilizing 200,000 cu. met. of water per 24 hours by the Marmier and Abraham process, but a confirmation of the claims made is very desirable.

The interesting process of Goldschmidt for obtaining very high temperatures of about 3,000 deg. C. by the combustion of aluminium mixed with metallic oxides was well exhibited and deserves mention, although only of indirect interest to electricians. The expense of the aluminium naturally limits its application, but this seems to be more than balanced in some cases by the other advantages. It is already in commercial use for obtaining pure metallic chromium and manganese for the iron industry, and for welding rails and tubes or mending broken iron parts.

In accumulators there was shown a general tendency, though not a universal one, to use Planté positives and Faure negatives, a combination which seems to have given the least trouble. Accumulators are now the rule and not the exception in continental lighting and traction stations. Now that the fundamental patents have run out in this country, we ought to use them more freely here. As an electrical flywheel and a comforting reserve in a central station, the accumulator has no equal.

It is impossible, of course, from mere inspection, or from catalogue data, to judge of the success of the light weight accumulator for transportable purposes, notably for the automobile. But from the awards of the jury which were based on reliable knowledge of their performance, the Fulmen, the Pulvis and the Phoenix were among the best of their kind; all three are French.

The most satisfactory development in primary batteries is that inventors—or perhaps the capitalists—seem to have at last been convinced that it is cheaper to burn coal than zinc.

A very interesting and promising method was shown in operation by its inventor, Rieder, for electrolytically engraving deep, hard steel dies, such as are used for pressing the reliefs on coins and for embossed work in general. A porous negative of plaster of Paris, saturated with chloride of ammonium, is lightly pressed against the steel blank and the metal is dissolved off electrolytically by a current, wherever the negative touches it. The cost is said to be only half that of the usual hand method.

The exhibitions of instruments were very fine, chiefly from France, England and Germany, but it would take too long to enter into a discussion of them here. That a d'Arsonval galvanometer is made with a sensitiveness of 1.2×10^{-10} amperes per m. m. deflection, is of interest; it is claimed to be the highest sensitiveness yet reached with that type of instrument. Among the station and laboratory instruments which are not generally used in this country, but which are very convenient, are the phase meters of Dobrowolsky, indicating directly the difference in phase. A curious, but characteristically European criticism of a certain world-renowned type of American instrument, was, that "they are bad because they are expensive."

The very general introduction of micanite, an American invention for generators and motors, is of interest.

The electric plant supplying the exhibition did not seem to be a success, judging from the very numerous stoppages and the excessive variations in the voltage.

The largest number of electrical exhibits were naturally, from France. Among the foreign countries Germany was far ahead of all others in importance, and promises to become the leading manufacturing country for electrical goods in Europe, if it is not so already. One company alone employs 14,000 hands, and ranks with our largest American company. It is of interest to us, that this successful company uses American methods quite largely. The Reichsanstalt, that creditable German institution, has no doubt contributed to the rapid strides made by that country in the electrical industries, and shows what government aid can do for the industries of a country. England has already started its Electrical Standards Laboratory of the Board of Trade, a very interesting and creditable government department, which was shown to our INSTITUTE this summer during its first official visit abroad. France has its "Central Laboratory," and is considering the enlarging of its government department; Russia has a large government electrical laboratory. The United States alone, among the large countries, has practically nothing of the kind.

Switzerland follows Germany in importance. The United States and England were inadequately represented in this department for reasons already mentioned, although there were some excellent exhibits from each. The lists in the catalogues cannot be taken as a guide in such a comparison, because a simple little device of no importance has the same prominence there as a large important exhibit of several thousand horse-power of machinery. Moreover many American exhibitors who were entered in the catalogues, did not exhibit. In one class alone, the number of actual exhibitors was only 40% of that in the catalogue of the United States exhibits, and many of these were quite small. It would therefore not be just to judge the state of this industry in our country, by the exhibits or by the awards.

A characteristic difference between American and foreign practice in manufacturing, as for instance such goods as dynamos and motors, is that here the manufacturer establishes certain well studied and well developed standard types and sizes of machines once for all, and then reproduces them in large numbers, making the parts interchangeable. The foreign manufacturer, on the other hand, constructs each machine according to the detailed specifications of the one ordering it. He argues that if he should make bids with standard sizes in stock, the purchaser would accept the bid of some one else who would construct the machines exactly according to the specifications. As a matter of fact, however, it was noticeable that those companies which have adopted the American method, were as a rule the most successful. There is also a field in and around Paris at least, for American methods of managing and operating electric tramways, as existing practice is there very poor.

Another difference is that here the manufacturer as a rule devotes his whole effort to a single class of goods, and makes these in large quantities, while abroad he attempts to make a large range of widely different kinds of articles; this seems practical only when each branch is a large business in itself.

Still another difference is in the fine external finishing of even those parts of an apparatus which are concealed. Their argument is that all parts of a well made apparatus ought to look well, and that it will then be handled with greater care and respect. Here we would consider it a useless expenditure of money to polish all the concealed mechanism of arc lamps, for instance. The foreigner, however, is apt to judge our goods from his standpoint, at least until he can be convinced of their advantages.

The Jury of Awards had many delicate questions to settle, both technical and diplomatic. While mistakes are possible, it is more than likely that complaints of exhibitors can generally be traced to unworthy or inadequate exhibits, or to circumstances beyond the control of the jurors. One-half the jurors were French and in the electrical group they were very liberal and generous to the foreign exhibitors, more so than to their own countrymen. If they erred at all, it was on the side of generosity for which they deserve our thanks instead of abuse. Only two of the United States jurors for the electrical group were members of the INSTITUTE.

The Electrical Congress was an international gathering of about 1,000 engineers and scientists interested in the subject of electricity, and as a convention it was a great success, giving an opportunity of making many acquaintances and friendships among men of the same calling in widely different parts of the world. The French deserve great credit for its organization and management. A large number of papers were read, varying in quality from very good to poor, reports of which have appeared and are appearing in the journals. The social features of the visits to the neighboring electrical installations were well arranged and very enjoyable. Our INSTITUTE was represented by all of its six delegates, three of whom were elected officers of the Congress. All of the official United States delegates were members of the INSTITUTE.

As a gathering of official delegates appointed by the various governments to settle questions concerning units, this Congress came very near accomplishing nothing at all. Had it not been for the efforts of two of the United States delegates, both members of our INSTITUTE, this very important feature of the Congress might as well have been omitted. It was due to the convincing appeals of our member, Mr. C. O. Mailloux, that the chamber of delegates reversed its former decision to take no official action on units and names, and adopted without a dissenting voice the recommendations of its committee, in which our Past President, Dr. Kennelly, ably represented our INSTITUTE. These adoptions were that the name of "gauss" be given to the C. G. S. unit of magnetic intensity or flux density, and "maxwell" to the C. G. S. unit of magnetic flux. The practical units will then generally be the kilogauss and the mega-maxwell. All the other propositions of the INSTITUTE were withdrawn in committee when it was found that they could not be adopted. The only other action taken by the official delegates was a unanimous expression of opinion that electrical energy should be considered as a property to be protected by law like any other.

The reason no further official action was taken concerning names and units, as suggested by the INSTITUTE, is, in the opinion of the writer, that our propositions were new to many of the delegates, not having been discussed fully in their different countries before the meeting of the Congress. At the International Congress of 1891 at Frankfort, when our INSTITUTE endeavored through its delegates to have the names gauss and henry adopted, the reason for the failure was the same, and in the report of our delegates[1] it was recommended that in future our propositions should first be thoroughly discussed in the societies and journals of the different countries, leaving to the Congress only the final decision on well understood propositions. Had this recommendation been followed in the present case we might have accomplished still more. Any further recommendations of the INSTITUTE should be decided upon as soon as practicable and be made the subject of international discussion in the journals and societies in preparation for the next International Congress, whenever that may be.

The first meeting which our INSTITUTE held abroad, was a memorable event and bids fair to be the beginning of a series of international meetings of electrical engineers. It brought the INSTITUTE into considerable prominence abroad, increased its influence, and afforded great pleasure to those of its members who attended. When it was first suggested by a member of Council some years ago, to hold a meeting this year in Paris, the proposition was met with some ridicule, but its success and the benefit the INSTITUTE derived from it, shows that the venture was not an unwise one, and that such meetings ought to be repeated. While we may have just pride in feeling that some branches of electrical engineering are better developed here than in other countries, and that our method of manufacturing certain classes of goods is superior, yet we should not forget that others who have worked equally hard in other countries often reach conclusions differing from ours, and which may well be worth our while to consider. Although our typically American practice of manufacturing standard types in large quantities and with interchangeable parts, undoubtedly has great advantages, yet that is the very method which tends to retard development in those types, as it makes one hesitate, perhaps too long sometimes, to make improvements. On the other hand the typically European method of building almost every machine differently, gives an excellent opportunity for developing them, but precludes wholesale manufacture at reduced cost. Such international meetings therefore can hardly fail to be of benefit to all who take part, as they enable one to find, through personal observation and personal intercourse, that which is the best the world over, just as

---

[1] TRANS. A. I. E. E. vol. 8, p. 546.

our home meetings bring before us the best in our own country. If we want to manufacture the best there is, especially if we want the foreigner to buy it from us, we should have international intercourse.

In London, our sister society, the Institution of Electrical Engineers, entertained us with true English hospitality for three well filled days, with a most delightful program, in which pleasure and instruction were harmoniously combined. It will long be remembered by the 28 or 30 of our members who attended, as one of the most enjoyable features of the whole meeting. In Paris the official joint meeting with the British Institution, held in the National Pavilion of the United States, through the courtesy of Commissioner Peck, was well attended and was followed by receptions of both institutions, visits to objects of interest, and the Electrical Congress, making a total of two well filled weeks of international intercourse between electrical engineers, and constituting one of the most important meetings in the history of the INSTITUTE.

The success of our first meeting abroad should encourage us to follow the excellent example of the Institution of Electrical Engineers by making official visits to the different foreign countries to study their practice and examine their work. Our foreign colleagues will then be encouraged to visit our country, as many of them have promised to do next year on the occasion of the Pan-American Exhibition in Buffalo.

Following the Inaugural Address, Mr. F. W. Roller exhibited and described the "Column Type of Indicating and Recording Volt and Ampere Meters," after which the meeting adjourned.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, November 23, 1900.

The 148th Meeting was held this date at 12 West 31st Street, and was called to order at 8:20 p.m. by President Carl Hering.

The Secretary:—At the meeting of the Executive Committee this afternoon the following Associate Members were elected :

Name.	Address.	Endorsed by.
Baldwin, George Porter	Sales Agent, John Martin & Co , 31–33 New Montgomery St., residence, 1806 Larkin St., San Francisco, Cal.	John Martin. F. V. T. Lee. T. E. Theberath.
Ballou, Warren James	Electrician, Woonsocket Elec. Machine & Power Co., Station No. 2, Woonsocket, R. I.	Tom H. Gregg. H. A. Storrs. Harry D. Reed.
Converse, V. G.	Engineer and Manufacturer, 3rd Street and Penn Ave. Pittsburgh, Pa.	P. N. Nunn. Chas. F. Scott. R. D. Mershon.
Chatelain, Mikail Andrejevitch de	Prof. of Electrical Engineering, Mining Institution and Electro-technical Institution, Wasily Ostrow, 10 Line No. 5, St. Petersburg, Russia.	Carl Hering. R. W. Pope. C. O. Mailloux.
Deeds, Edward Andrew	Head of Engineering Department National Cash Register Co., Dayton, O.	G. D.Shepardson. E. P. Roberts. F. B. Corey.
Hafer, George, Jr.	Gen. Supt. and Elec. Eng. Cincinnati Gas Co., Elect. Dept., Cincinnati, O.	Joseph Sachs. Bert L. Baldwin. C. Stowe Reno.
Kelsey, James Cezanne	Switchboard Trouble Mgr. N. W.Telephone Exchange Co., Minneapolis, Minn.	John. J. Carty. G. D.Shepardson. Chas.L.Pillsbury.
Leyden, Harry Russell	Mgr. Hamilton Elec. Lt. & Cataract Pr. Co., Hamilton, Ont.	C. C. Chesney. W. F. White. R. W. Pope.

Lowther, Christopher Meyer	Sales Engineer Crocker-Wheeler Co., New York; res., 168 Arlington Ave., East Orange, N. J.	F. V. Henshaw. Gano S. Dunn. E. M. Archibald.
Sethman, George Henry	Mechanical and Electrical Engineer, Skinner & Sethman, 2248 Irving St., Denver, Colo.	J. W. Stearns. C. E. Doolittle. Lewis Searing.
Springer, Frank W.,	Assistant Professor Electric Engineering, University of Minn., Minneapolis, Minn.	G. D. Shepardson. John J. Flather. Chas. L. Pillsbury.
Stern, Philip Kossuth	Practicing Electrical and Mechanical Engineering, 180 Fulton St., N. Y.	T. C. Martin. Fred A. LaRoche. Ralph W. Pope.
Snyder, Nathaniel Marion	County Surveyor for Scotts Bluff Co., Gering, Nebraska.	Ralph W. Pope. C. O. Mailloux. Saml. Sheldon.
Walkem, George Alexander	Electrical and Mechanical Engineer, P. O. Box 595 Vancouver, B. C.	Louis A. Herdt. Ralph W. Pope. K. G. Dunn.
Woodworth, Leon Byron	Electrical Engineer, New Heriot Gold Mining Co., Johannesburg, Transvaal.	J. W. Kirkland. M. A. Oudin. W. L. R. Emmet

Total, 15.

The following Associate Members were transferred to membership:

Approved by Board of Examiners, October 12, 1900.

W. A. Layman,	Assistant Manager and Treasurer, Wagner Electric M'f'g. Co., 2017 Locust St., St. Louis, Mo.
Ferd. Schwedtmann,	General Superintendent, Wagner Electric M'f'g Co., 2017 Locust St., St. Louis, Mo.
Louis J. B. Wall,	Full Partner, Splatt, Wall & Co., Perth, Western Australia.

Gentlemen, last spring a bill was introduced in the National Congress looking to the establishment of a standardizing bureau in connection with the Bureau of Weights and Measures in Washington. The Council appointed a special committee to take action in regard to this matter and use what influence we had in carrying the measure through. Congress adjourned before any action was taken, although a Congressional Committee reported favorably upon it. It is now about to be taken up again, and in accordance with the recommendation of the Chairman of our Committee a resolution has been prepared to be brought before the Institute to-night which, it is supposed, will have some effect in aiding arguments in favor of this measure. And I wish to assure you, before this matter is brought up, that it has received the earnest consideration of the Council and the Committee, and you will remember in September last Prof. Carhart read a paper in which he gave arguments in favor of it, so that the Institute is already committed in favor of doing what can be done toward the passage of the bill.

THE PRESIDENT:—Dr. Sheldon has a draft of resolutions which are to be offered at this meeting.

DR. SAMUEL SHELDON:—Mr. President, the Committee has adopted this form:

WHEREAS, bills "to establish the National Standardizing Bureau" were introduced in the Senate and in the House of Representatives, numbered and dated S. 4 90, May 14, 1800, and H. R. 11850, May 5, 1900, respectively;

WHEREAS, the purpose of the said bills is to provide for establishing and operating a bureau for the construction, custody and comparison of standards used in scientific and technical work, the testing and calibration of apparatus and the determination of physical constants, and the properties of materials;

WHEREAS, the necessity of such a bureau is universally recognized;

WHEREAS, such bureaux have already been established in several European countries, and are being established in others;

It is resolved that we, the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, in meeting assembled, this 23d day of November, 1900, strongly endorse those bills and recommend their passage by Congress.

The resolutions were adopted as read.

THE PRESIDENT:—The next thing in order is the paper by Mr. Behrend on "The Mechanical Forces in Dynamos Caused by Magnetic Attraction."

A paper presented at the 148th Meeting of the American Institute of Electrical Engineers, New York, President Hering in the Chair, November 23d, 1900.

ON THE MECHANICAL FORCES IN DYNAMOS CAUSED BY MAGNETIC ATTRACTION.

BY B. A. BEHREND.

Some years ago, when designing with Dr. Behn-Eschenburg alternating current machinery for the Oerlikon Engineering Works, Switzerland, we encountered formidable difficulties in diminishing the air-gaps in induction motors and in inductor generators. Everybody who has designed large generators or motors with small clearance, is aware of the tremendous mechanical effect of the magnetic forces, and of the necessity for abolishing their cause lest an otherwise successful design be balked by the bending of the shaft or even by the collapse of the magnetic frame. It was therefore of the greatest importance to us to calculate as exactly as possible the mechanical effects that were produced by unequal distribution of the lines of induction around the circumference of the armature, if the axes of armature and field were not coincident but eccentric.

In the text-books on dynamo-electric machinery this subject is generally very briefly treated and a formula is given which allows the calculation of the mechanical force of a piece of iron in a uniform magnetic field formed by two parallel surfaces, as represented in Fig. 1. This, however, is a hypothetical case of hardly any practical importance, if I except the device designed by the Oerlikon Works for counterpoising the heavy shafts and wheels of vertically arranged turbines. It is probably given for the sake of its simplicity and as the magnetic analogy to Lord Kelvin's absolute guard-ring electrometer.

From Maxwell's dynamical theory of the stresses in the magnetic field follows that the attraction between the armature *A* and the field *F* is equal to

$$(1)\ldots\ldots\ldots\ldots\ldots\ldots\quad Z = \frac{1}{8\pi}\,\mathcal{H}\,\mathcal{B}\,S.$$

In this formula $\mathcal{H}$ is the magnetizing force, $\mathcal{B}$ the induction, *S* the surface penetrated by the lines of induction. As all quantities are expressed in C. G. S. units, $\mathcal{B}$ is measured in dynes.

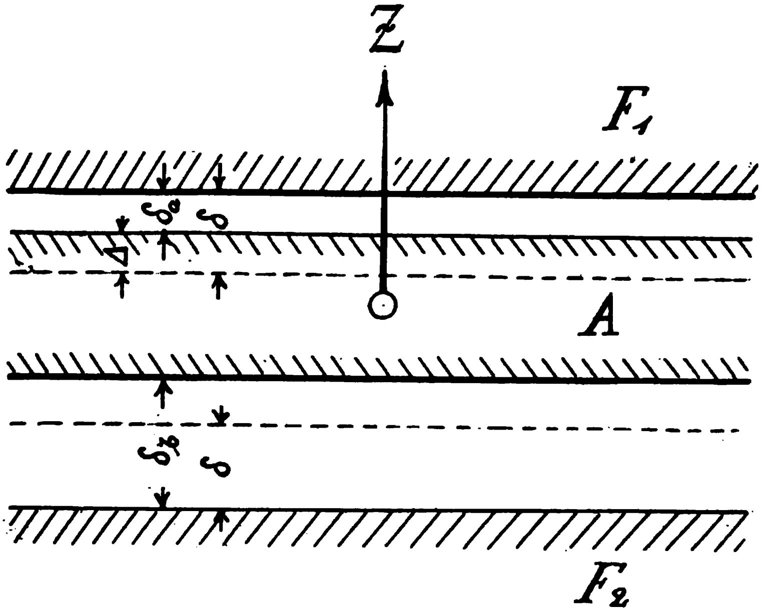


FIG. 1.

The formula (1) is generally, though incorrectly, written thus:

$$(1a)\ldots\ldots\ldots\ldots\ldots\ldots\quad Z = \frac{1}{8\pi}\,\mathcal{B}^2\,S.$$

As in air $\mathcal{B}$ is numerically equal to $\mathcal{H}$, the formula (1*a*) gives the same numerical result as (1), but it should not be forgotten that $\mathcal{B}$ and $\mathcal{H}$ are two quantities as different in kind as mass and force.

With the help of (1) we can write down at once the resulting attraction of the surfaces F_1 and F_2 upon the body *A*.

If A is in the middle between F_1 and F_2, the distance between A and F_1 is equal to the distance between A and F_2; we will denote it by δ. The unsymmetrical position of A is determined by the clearances δ_a above A, and δ_b below A. Similarly we denote the induction in the air-gap above A by the index a, and below A by the index b. The induction that prevails if A is in the symmetrical position is denoted by $\mathfrak{B}$ without an index.

We now have

$$Z = \frac{S}{8\pi}\left(\mathfrak{B}_a^2 - \mathfrak{B}_b^2\right)$$

We obviously can express $\mathfrak{B}_a$ and $\mathfrak{B}_b$ by $\mathfrak{B}$, viz.:

$$\mathfrak{B}_a = \mathfrak{B}\,\frac{\delta}{\delta - \Delta}$$

and

$$\mathfrak{B}_b = \mathfrak{B}\,\frac{\delta}{\delta + \Delta}$$

hence,

$$Z = \frac{S}{8\pi}\,\mathfrak{B}^2\left[\left(\frac{\delta}{\delta - \Delta}\right)^2 - \left(\frac{\delta}{\delta + \Delta}\right)^2\right]$$

This can be written thus:

$$Z = \frac{S}{8\pi}\,\mathfrak{B}^2\left[\frac{1}{\left(1 - \frac{\Delta}{\delta}\right)^2} - \frac{1}{\left(1 + \frac{\Delta}{\delta}\right)^2}\right]$$

$$= \frac{S}{8\pi}\,\mathfrak{B}^2\left[1 + \frac{2\,\Delta}{\delta} + \left(\frac{\Delta}{\delta}\right)^2 - 1 + \frac{2\,\Delta}{\delta} - \left(\frac{\Delta}{\delta}\right)^2\right]$$

Neglecting $\left(\frac{\Delta}{\delta}\right)^2$ in the denominator as a very small quantity, we arrive at the very simple expression of Z in dynes

$$(2)\ldots\ldots\ldots\ldots\ldots\ldots Z = \frac{S\,\mathfrak{B}^2}{8\pi}\cdot\frac{4\,\Delta}{\delta}$$

This expression of the attractive force is very perspicuous, and it permits of rapid and easy calculation, as δ and $\mathfrak{B}$ are known from the design. The only drawback, great enough, however, to make this formula inapplicable to dynamos, is that it supposes that by a displacement Δ the air-gap is equally diminished at all parts of the circumference, which would be true in dynamos only if the diameters of armature and field were infinitely great, and very nearly in bipolars in which the arc subtended by the pole is small. As will presently be shown, this formula yields results for Z considerably greater than the real values, and this is what should be expected as in the case of dynamos a certain displacement of the rotor causes an equal diminution, or increase, of the air-gap only in the one point lying in a plane laid through the axes of rotor and stator, whereas in a plane perpendicular to this no diminution or increase of the air-gap takes place. Hence the whole surface S is not active, but only part of it.

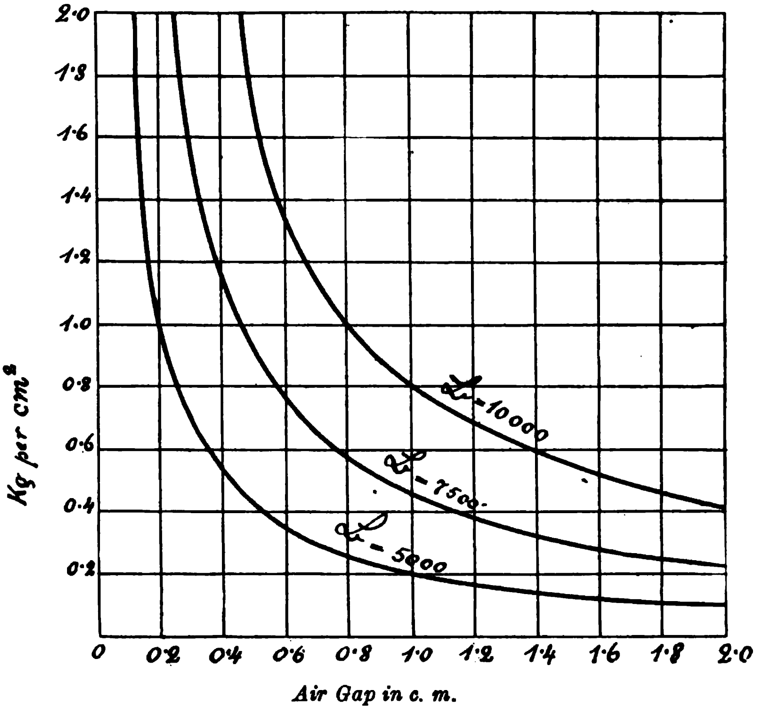


Fig. 2.—Curves illustrating the Magnetic Attraction Z as a Function of the Air Gap, and of the Induction with an Eccentricity Δ — 0.05 c. m.

In a machine whose characteristic has been measured, $\mathfrak{B}$ can easily be calculated, whereas it would be difficult to find $\mathfrak{B}_a$ and $\mathfrak{B}_b$. In fact, in order to find their numerical values, one would have to calculate $\mathfrak{B}$ first, and then express $\mathfrak{B}_a$ and $\mathfrak{B}_b$ by means of δ_a and δ_b.

Our formula (2) shows that for a given induction $\mathcal{B}$ the magnetic attraction is directly proportional to the displacement Δ, inversely proportional to the air-gap δ. Assuming that a certain eccentricity of armature and field will be unavoidable, we see that Z increases rapidly with a diminution of δ.

To give a clear idea of this relation I give some curves in Fig. 2, the ordinates of which represent the magnetic pull in kg. per cm.^{2}, while the abscissæ represent the air-gap in cm. The displacement Δ is assumed to be equal to 0.05 cm. A glance at Fig. 2 is sufficient to make a designer wary when the diameters of his machines assume values of fifteen feet and more, the frames having to resist collapse like the flues of boilers.

But my object in presenting this paper is not to expound the corollaries of formula (2), well-known as they certainly are to every thoughtful electrician. I want to deduce a new formula strictly applicable to the case represented by dynamos, and show its agreement with observation.

For this purpose let us consider the case of two cylinders as represented by Fig. 3. We assume that there is all around the circumference the same magneto-motive force $\int \mathcal{H}\, d\,\delta$, and that the lines of induction choose the shortest path between the two surfaces. Their density is then inversely proportional to the clearance.

With reference to Fig. 3, we have then:

$$\delta_a = \delta - \Delta \,.\, \cos a$$

Δ is defined by

$$\Delta = \frac{\delta_b - \delta_a}{2}$$

Hence

$$\frac{\mathcal{B}}{\mathcal{B}_a} = \frac{\delta_a}{\delta} = \frac{\delta - \Delta \,.\, \cos a}{\delta}$$

$$\mathcal{B}_a = \mathcal{B} \,.\, \frac{1}{1 - \frac{\Delta}{\delta} \,.\, \cos a}$$

The magnetic attraction acting upon a surface element of the area $b\ R\ d\ a$, in which b is the width of the laminations, directed towards the center, is

$$d f_0 = \frac{1}{8\ \pi}\ \mathfrak{B}_a^2\ b\ R\ da$$

The horizontal components of this force on either side of the line of symmetry balance each other, the remaining vertical component being

$$d f = \frac{1}{8\ \pi}\ \mathfrak{B}_a^2\ b\ R\ da \cos\ a$$

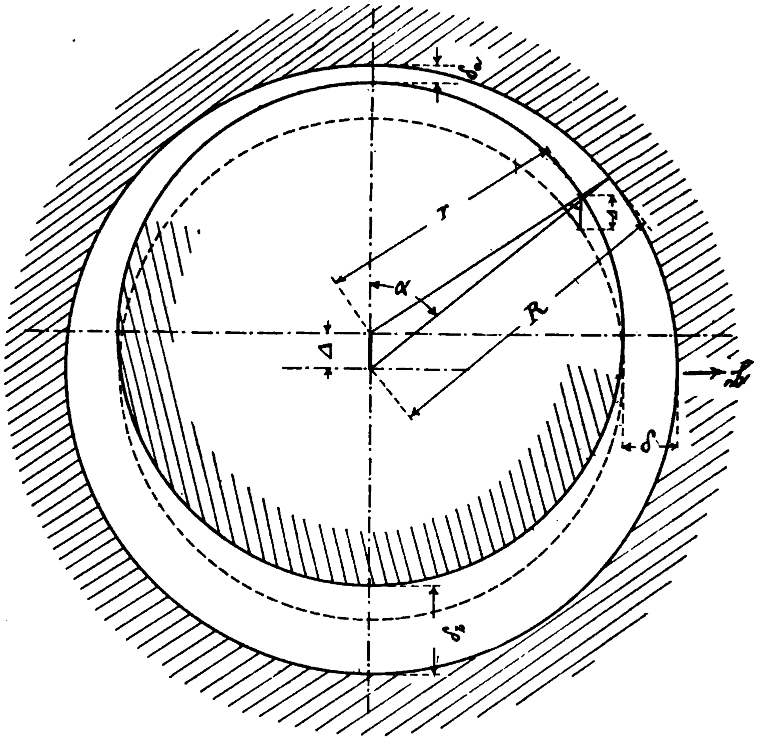


Fig. 8.

Substituting into this expression the value for $\mathfrak{B}_a$ found above, we have

$$d f = \frac{1}{8\ \pi}\ b\ R\ \mathfrak{B}^2\ \frac{\cos\ a\ da}{\left(1 - \frac{\Delta}{\delta} \cos\ a\right)^2}$$

$$= \frac{1}{8\pi} b\, R\, \mathcal{B}^2 \frac{\cos a\, da}{1 - \frac{2\Delta}{\delta}\cos a + \left(\frac{\Delta}{\delta}\cos a\right)^2}$$

Neglecting $\left[\frac{\Delta}{\delta}\cos a\right]^2$ as small in comparison with $\frac{2\Delta}{\delta}\cos a$, we get

$$df = \frac{1}{8\pi} b\, R\, \mathcal{B}^2 \frac{\cos a\, da}{1 - \frac{2\Delta}{\delta}\cos a}$$

$$= \frac{1}{8\pi} b\, R\, \mathcal{B}^2 \frac{1 + \frac{2\Delta}{\delta}\cos a}{1 - \left[\frac{2\Delta}{\delta}\cos a\right]^2} \cos a\, da$$

$$= \frac{1}{8\pi} b\, R\, \mathcal{B}^2 \left[1 + \frac{2\Delta}{\delta}\cos a\right] \cos a\, da$$

By integrating this expression between the limits 0 and $\frac{\pi}{2}$ we find the vertical component of the magnetic attraction in one quadrant. Hence

$$\int_0^{\pi/2} df = \frac{1}{8\pi} b\, R\, \mathcal{B}^2 \int_0^{\pi/2} (1 + \frac{2\Delta}{\delta}\cos a)\cos a\, da$$

$$= \frac{1}{8\pi} b\, R\, \mathcal{B}^2 \left[\int_0^{\pi/2} \cos a\, d\, a + \frac{2\Delta}{\delta}\int_0^{\pi/2} \cos^2 a\, da\right]$$

$$= \frac{1}{8\pi} b\, R\, \mathcal{B}^2 \left[\Big|_0^{\pi/2} \sin a + \frac{2\Delta}{\delta}\Big|_0^{\pi/2} \tfrac{1}{4}\sin 2a + \frac{2\Delta}{\delta}\Big|_0^{\pi/2} \frac{a}{2}\right]$$

$$(8a) \qquad f_a = \frac{1}{8\pi} b\, R\, \mathcal{B}^2 \left[1 + \frac{2\Delta}{\delta}\frac{\pi}{4}\right]$$

Similarly we find for the vertical component of the attractive force directed downwards the expression

$$(3b) \qquad f_b = \frac{1}{8\pi} b R \mathfrak{B}^2 \left[1 - \frac{2\Delta}{\delta}\frac{\pi}{4}\right]$$

Hence

$$(3c) \qquad f_a - f_b = \frac{1}{8\pi} b R \mathfrak{B}^2 \frac{4\Delta}{\delta}\frac{\pi}{4}$$

This is the resultant of all the vertical components on one side of the line of symmetry. To find the total force we must multiply by two and we thus arrive at

$$(3) \qquad Z = \frac{1}{8\pi} S \mathfrak{B}^2 \frac{2\Delta}{\delta} \text{ dynes,*}$$

in which

$$(3d) \qquad \begin{cases} S = \pi R b \\ \Delta = \dfrac{\delta_b - \delta_a}{2} \end{cases}$$

A comparison of formulas (2) and (3) shows at a glance that (2) yields an attractive force twice as large as (3).

Formula (3) is of great practical importance and interest as it is the correct expression for the magnetic attraction between two cylinders the axes of which are slightly displaced towards each other.

I will now give the result of some experiments on magnetic attraction which were made with a 300-H. P. inductor generator for 2,000 volts, a cross-section of which is represented in Fig. 4. The data of this machine were the following:

Number of R. P. M.	166
Frequency per second	50
Pole-horns on each side	18
Bore of field	260 cm.
Width of laminations	28 cm.
Number of coils on each armature	36
Number of turns of each coil	7
All coils in series.	
Air-gap above	0.26 cm.
Air-gap below	0.46 cm.

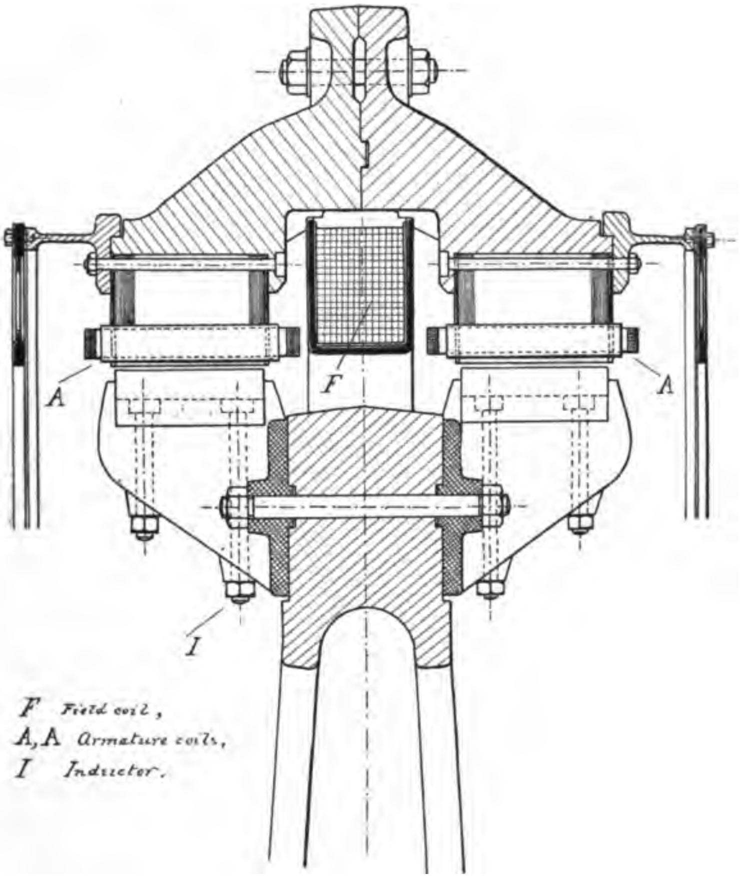
The bearings of the generator were opened and the field was excited while the inductor was standing still. At 18 amperes

---

*The derivation of this formula was looked over by Dr. Behn-Eschenburg. I feel, therefore, confident that it is not marred by any important mistake.

excitation the inductor *I*, with shaft weighing 8,400 kg., was lifted up from the bearings until it clung to the armature frame. The excitation was then lowered to eight amperes, when inductor and shaft dropped back into the bearings.

(1) At 18 amperes excitation and 50 P. P. S. the generator gave 1,400 volts on open circuit, whence follows $\mathcal{B} = 5900$.



Cross-section of inductor generator on which tests were made. Bore 260 cm.

FIG. 4.

(2) At eight amperes excitation and 50 P. P. S. the generator gave 640 volts on open circuit, whence $\mathcal{B} = 2700$. But it must be remembered that in our attraction experiment we should take into consideration that the magnetism at eight amperes excitation was attained by lowering the excitation, and as in inductor

generators the descending curve of magnetization lies often as much as 20% above the curve of ascending magnetization, this should be taken into account. In a paper published by the *Electrical World and Engineer*, I have enlarged upon this point and I may therefore here refer to it.[1] We therefore assume that $\mathfrak{B}$ is 3100 instead of 2700; of course, there hangs the flavor of arbitrariness about such an assumption, but it surely is not far from the real value.

For test (1) we have to substitute the following values into formula (3):

$$S = 9350 \text{ cm.}^2$$
$$\mathfrak{B} = 5900 \text{ C. G. S.}$$
$$\Delta = 0.1 \text{ cm.}$$
$$\delta = 0.36 \text{ cm.}$$

Hence

$$Z = \frac{9350 \times 5900^2}{8\,\pi} \, \frac{2 \times 0.1}{0.36} \text{ dynes}$$

$$Z = 7400 \text{ kg.}$$

For test (2) we have:

$$S = 9350 \text{ cm.}^2$$
$$\mathfrak{B} = 3100 \text{ C. G. S.}$$
$$\Delta = 0.36 \text{ cm.}$$
$$\delta = 0.36 \text{ cm.}$$

Hence

$$Z = \frac{9350 \times 3100^2}{8\,\pi} \, \frac{2 \times 0.36}{0.36} \text{ dynes}$$

$$Z = 7340 \text{ kg.}$$

The observed value was 8400 kg. Considering the many sources of error, the agreement between observation and formula (3) is fairly satisfactory. On account of the fringes of the magnetic field at the edges of the pole-pieces, the determination of the exact value of S is left to the judgment of the designer. As the attractive force is also directly proportional to the square of the total flux, and inversely proportional to the surface S, it follows that if we had estimated S 5% too large, Z according to formula (3) must be 5% too small.

I hope that formula (3) will make some friends among designing engineers.

---

[1] *Electrical World and Engineer*, Jan. 20, 1900.

Erie, Pa., October, 1900.

DISCUSSION.

THE PRESIDENT:—Mr. Behrend has developed in this paper a most interesting formula, and one which is extremely simple. It is for making a calculation which formerly was very difficult to make, and one which is of special importance with induction motors where the air-gaps are so extremely small. The Oerlikon Company, I understand, have a rule to make the air-gaps of such motors one-tenth of one per cent. of the diameter of the moving part, that is, one one-thousandth of the diameter. In such cases these forces become very important. The paper is open for discussion.

MR. GANO S. DUNN:—I welcome the development of a formula of this kind, because it will very materially help in those operations of designing in which magnetic pulls have to be calculated; and while in direct current designing the matter is not of such great importance as it is in alternating current, where, on account of the necessity of high frequency, the polar construction has to be forced, yet it is customary now in specifications for direct current generators to call for the amount of unbalanced pull that will occur on an armature for a given eccentricity. This, that the strains on the engine shaft may be properly calculated.

The bringing up of this subject calls attention to a feature of design on which I have always had strong convictions—namely, the size of air-gaps. You have just mentioned that the gaps of the Oerlikon Company are figured at one-tenth of one per cent. of the diameter for induction motors—and it is well known that the gaps used in induction motors and by many builders of direct current machinery are extremely small. I think this is wrong and contrary to the best mechanical engineering practice. To my mind one of the great disadvantages of the induction motor, one of the disadvantages from which it must be freed if it is to take its proper place in the distribution of power, is this small air-gap. The machines with which I have had to do have always been characterized by large air-gaps so as to avoid the trouble which has caused the presentation of Mr. Behrend's paper. I consider that for a machine whose armature is five feet in diameter the air-gap should be half an inch. This large air-gap makes displacement of the armature from its center relatively unimportant Were the gap three-sixteenths of an inch, as it is frequently made, an eccentricity of the armature of a thirty-second of an inch, which is not uncommon, from the wear of bearings or the settling of foundations, would make a very serious distortion or perturbation in the distribution of the flux from the poles, since it is one-sixth of the total gap; whereas, such distortion or perturbation is practically insignificant if the gap is as large as I have said.

With regard to the stresses in induction motors I should like to ask, as a matter of information, whether it is a fact that when an induction motor is running, and has a certain amount of eccentricity in its armature, there is an unbalanced pull between the armature and the stator resulting from that eccentricity. I have always believed so; but in discussing this question with a member of the INSTITUTE at its general meeting in May, a man who is very well posted, he assured me that while such a phenomenon took place in direct current machines, in synchronous motors and that character of apparatus, it was entirely absent in induction motors. If the facts could be brought out in the discussion here I think it would be very useful. I am sure that the formula of Mr. Behrend will help us to determine these strains resulting from eccentricity much more readily than we have been able to determine them before, when we have had to figure them on a trial and error method.

MR. C. O. MAILLOUX :—The effect of displacement of an armature in a magnetic field is not to be neglected, even in the case of direct current machines, especially when they are of large size. It may happen that in some cases when the field becomes fully excited there will result from the difference of magnetic pull exerted by the different poles a component which may tend either to increase the apparent weight of the armature or to decrease it. This effect is of special importance when it is attempted to determine the efficiency of a dynamo, for instance, by the so-called indicator method. I have had some very amusing experiences in that connection which incidentally illustrate the entire uselessness of the indicator method as a means of determining the efficiency of a dynamo. I have seen cases (in units of 150 to 250 K.W. connected direct to slow speed engines) where the vertical component due to armature weight apparently, changed when the load came on; that is to say, the pull exerted on the bearings was not the same when it was running light, as when it was running loaded. This is particularly apt to be the case with dynamos whose armatures have several "paths" in parallel, especially when the brushes are not set in such a manner as to give absolute E.M.F. balance, or if the poles themselves are not thoroughly balanced, that is to say, if the different magnetic circuits have unequal fluxes. I have seen cases where one obtained some interesting results, if one took indicator cards of the unit when running without external load, that is to say, when running with only the field excitation, or even without the excitation (more especially in the latter case), and then undertook to use this "load" as the constant (representing various losses), to be subtracted from the indicator results for the total load carried, when the unit ran fully loaded. I have seen the efficiency come out as a hundred and one or two per cent. This is simply due to the fact that after the load came on, the armature was apparently lifted and its friction load seemed to have decreased instead of increasing. Hence, on deducting from the total indicated load the "loss load" obtained when the engine ran light, the difference (representing the "power applied to the dynamos," for generating the external or useful output of electrical energy), is smaller than it ought to be, and the efficiency comes out apparently high. The error would perhaps not be suspected excepting in cases where the percentage obtained is unexpectedly high, or where one may be able to account otherwise for the discrepancy in efficiency. The phenomenon first came to my attention in some cases where I knew that I could, by the "method of losses," account for seven or eight or more per cent. of loss in the generator set, and, when I found that, by the indicator method, the loss was apparently only one or two per cent., I immediately suspected that there was something wrong. This trouble occurs even with machines having large air-gaps, and it is one which should be carefully considered, not only with reference to the efficiency of the machine when operated under full load, but also on account of other troubles to which it gives rise.

I should also have added that when the displacement of the field is of the opposite kind, a contrary result may be expected and is often found—namely, instead of the efficiency being greatly increased, it is very much reduced. In such cases it is to be presumed that the vertical or weight component, instead of being decreased as the load comes on, is considerably increased thereby, and consequently the friction load is also increased, while the load is turned on. I ought to state that these observations were made by me some years ago, before the "method of losses" (now the only method endorsed by the A. I. E. E.) had superseded the indicator method.

MR. BEHREND:—May I shortly answer the two speakers? First, I should like to make a few remarks about what was brought forth just now about the efficiency of dynamos being lowered by an eccentricity of the armature. Now I understood you that it is not always necessary to have an eccentricity causing magnetic strains in order to get a lower efficiency than the one that might be calculated from certain data that you have. Well, I think there is an explanation of this. Most high speed dynamos are not very well balanced; that is to say, I mean the rotating part is not very well balanced; it often has a heavy point. Now a heavy point causes a perfectly astounding amount of waste of energy. You can easily make an experiment on this by simply taking a fly-wheel and putting a bolt into the rim on one side, running it with an electric motor and measuring the power, and then balancing the wheel perfectly, and measuring the power again. The loss of energy is perfectly surprising. It need, therefore, not necessarily be an eccentricity and a negative pull consequent on that, but simply a mechanical defect of the armature perfectly sufficient to explain a certain increase in the losses.

As to Mr. Dunn, the first speaker, I wish to say that of course it offends the feeling of a mechanical engineer if he has to decrease his air-gap very much; but in some cases he simply *has* to do it, because if your poles get close together, and they always do if you have to build large dynamos for high frequencies or slow speeds, in order to avoid getting tremendous diameters which you cannot deal with. Therefore you have to lower your air-gap in order to avoid too much leakage. But I am indebted to the speaker for having brought forth this point.

As to the mechanical pull in induction motors I wish to make a statement which, however, I ask not to take down, because I have not carefully thought about the matter.

MR. MAILLOUX :—I wish to state for the information of Mr. Behrend that the particular dynamos in which I noticed the phenomena referred to in the most striking degree, were not driven by high speed engines. They were slow speed engines of the Corliss type, in which the shaft diameter of the 250 K.W. unit was 18 inches at the middle and 15¼ inches at the main bearings, the design, material and workmanship being certainly of the very highest grade that can be produced in this country. I do not believe, therefore, that any of the disturbances which he refers to could possibly, in the cases referred to by me, have acted as a source of error or as a cause of discrepancy in the results.

MR. HENRY FLOY :—I would like to support Mr. Behrend's theory with regard to the induction motors. I know from practical experience in some cases that have come to my notice, that if the rotating part is a little out of the center, the magnetic influence has been enough to bend the shaft to such an extent as to pull the rotating part right up against the stator and prevent its rotating at all.

MR. BEHREND :—I merely wish to say that my remarks about the decrease of efficiency do not apply to the case brought forth by the speaker. I mean that if you have to deal with slow speed engines, then the effect of a poorly balanced armature is not so serious. I did not know that the dynamos that the speakers mentioned were slow speed dynamos.

MR. DUNN :—I think that perhaps one reason why designers of electrical machinery have been tempted to use such small air-gaps as have been used, has been because they have not realized that such tremendous strains are introduced into the machine by the unbalancing that takes place. If Mr. Behrend's formula, by making calculations of these strains very much more simple than has heretofore been possible, shall divert us from small air-gaps, I think it will lead us to accomplish a great deal in a very useful work.

MR. C. O. C. BILLBERG .—I beg to call the speaker's attention to the fact that in alternating current machinery we are dealing with such a low magnetic density that we cannot afford to have a large air-gap. In direct current machinery we may use from 16,000 to 17,000 lines of force per square centimetre, but in alternating current machinery we have to limit ourselves to from 2,000 to 5,000.

Mr. Dunn:—I was not speaking solely from the point of view of direct current machinery, and I realize the sacrifice that would have to be made to get these large air-gaps in induction motors. But I wish to make the point that I think the sacrifice worth making. What does it avail us to have a comparatively low power factor if the machine is going to give us any trouble whatever mechanically? I consider that mechanical performance is the very first requisite, and that we ought to sacrifice other things to get it, even air-gaps.

The President:—I would like to ask Mr. Behrend, who is quite familiar with the design of induction motors, whether it is not a fact that the size of the air-gap is of much more importance in induction motors than in continuous current motors, and would not the sacrifices by making the air-gap large in induction motors, be much greater than they would be in continuous current motors?

Mr. Behrend:—I think it is hardly possible to build induction motors with large air-gaps owing to the tremendous exciting currents, or no load currents, produced by a large clearance; your motor would be electrically so poor as not to be utilizable at all.

As to the densities in generators I wish to say that of course 3,000 per square centimetre is by no means the upper limit. It is the upper limit if you have to deal with frequencies between 60 and 80, but if you can work at freqnencies of 42 to 50, you may, I think, safely adopt inductions between 6000 and 7500. In inductor generators the frequency is, loosely speaking, only one-half; as far as the losses through hysteresis and eddy currents are concerned. Therefore the inductions in these machines may be about 10,000 or 12,000 in the air-gap; 12,000 is by no means an outrageous induction adopted for inductor machines of a frequency of 50.

Mr. Frederick V. Henshaw:—One of the recent speakers I understood to explain the necessity for a short air-gap in an induction motor as being due to the fact that the density in the air-gap was very small, and it seems to me that point requires a little clearing up. If the density is very small, then I should think they could use large air-gaps. If the density was very great why then small air-gaps would be in order.

Mr. Billberg:—I was speaking about the induction in the iron, the density in the air-gap will be smaller yet. It is not a question of using a small density, it is a question of the cost of getting the magnetic lines of force through the air-gap.

Mr. Henshaw:—My point was that if the density was very high, it would cost so much more. The fact that the density is low and the air-gap small, is the only thing that makes the induction motor commercially possible at all.

Dr. Sheldon:—I am not sure whether I know anything about this or not. But the Edison Illuminating Company of Brooklyn has issued a little pamphlet to people who intend attaching induction motors to its three-phase circuits, which says that induction motors of certain sizes, which are to be attached to its circuits, shall not have a starting current of more than twice the normal, full-load working current. Now, if the air-gap is large, I believe that the starting current is quite large. And if the air-gap is small the starting current is not necessarily large. The cause of the former is magnetic leakage. There are lines which do not link between the stator and the rotor. Some of the lines which are produced by the current in the primary, encounter the large reluctance in the air-gap and leak around back home again without having linked with the windings in the secondary. Therefore it is necessary, in order that a motor shall start satisfactorily, to have a small air-gap.

[COMMUNICATED AFTER THE MEETING BY DR. A. E. KENNELLY.]

The paper under consideration conveys two main propositions, namely:

1st. That if a dynamo armature instead of being round, had a square contour, and were symmetrically located within a symmetrically slightly larger square field-polar cavity, and a constant magnetic difference of potential maintained between the opposing parallel plane surfaces of field and armature, so that the flux density in the air-gap should be inversely proportional to the thickness of the said air-gap; then if one of the faces of the square armature be displaced parallel to itself through a small distance Δ, the total resultant magnet pull upon the square due to the unbalanced magnetic forces on the sides having respectively a reduced and increased air-gap is $\frac{S\mathfrak{B}^2}{8\pi}\cdot\frac{4\Delta}{\delta}$ dynes, the surface δ being in this formula the surface of one of the sides of the square armature.

2d. The proposition contained in the paper for the case of a round armature is virtually equivalent to resolving the round armature into a square armature of the same breadth, and of a hypothetical perimeter equal to the actual circumference. The displacement of the armature takes place parallel to one of its sides through the distance Δ as before. The total resultant magnetic force acting upon the real circular armature will be the same as the computed force acting upon the ideal square armature.

Consequently the two propositions in the paper actually resolve into a single proposition on the hypothesis that a round armature is reduced hypothetically to a square armature of equal perimeter.

In the case of multipolar continuous-current generators, except where the air-gap is very small relatively to the dimensions of the machine, the resultant magnetic forces are usually not so serious as the dissymmetry of electromotive forces produced. In multipolar machines the eccentricity of the rotor may produce marked unbalancing of the electromotive forces in the segments of the armature, unless special precautions are taken to prevent this.

It is interesting to notice that the agreement between the formula and the first observation reported in the paper is so good, although the second observation, when the rotor was in contact with the stator, was not so good. Manifestly, however, in the latter case a constant difference of potential between the two sides of the air-gap could not be maintained, and the result would be vitiated by this cause alone, so that close agreement could not be expected.

[Reply by the Author.]

In reply to Dr. A. E. Kennelly's interesting communication, I wish to say that it is perfectly true that the second case treated in my paper may be reduced to the first by assuming an ideal square armature in a square field having the same perimeter as the circular armature in the circular field, but Dr. Kennelly doubtless arrived at this interesting way of putting the results of my paper by contemplating the formulas, and I do not see at present how his comparison could be reached by a short cut. I entertain no doubt, however, that a simple graphical solution is possible.

As far as I am acquainted with dynamo-design, I believe that the winding of the armatures of large multipolar machines built by cautious engineers is always such as to neutralize the inequalities of the electromotive forces in the various segments. Eccentricities, though small, are unavoidable, and the winding known as that of Arnold, the device of Lammet, Mordey's connections, they all have been invented to meet the difficulties mentioned by Dr. Kennelly. The last-mentioned has been adopted by the Oerlikon works in their large 900 H. P. direct current generators at Rheinfelden; machines that had to be built with 32 poles for 55 R.P.M. and 8000 amperes.

A paper presented at the 148th Meeting of the American Institute of Electrical Engineers, New York, President Hering in the Chair, and Chicago, Nov. 23, 1900.

THE PLANT OF THE ST. CROIX POWER CO. OF WISCONSIN.

BY HENRY FLOY.

INTRODUCTORY.

The considerable number of high-tension long-distance transmission plants already in successful operation, might not render the completion and starting of a 25,000-volt plant of any particular interest, except that in all engineering work and especially in electrical lines, the "newest" usually means something of a change from, and improvement upon anything previously constructed.

There are, however, some features both hydraulic and electrical connected with the plant of the St. Croix Power Company, recently put into operation which I think will prove of more than ordinary interest to the members of this INSTITUTE.

GENERAL DESCRIPTION.

About two years ago the St. Paul Gas Light Company of St. Paul, Minn., owing to increasing business, the depreciation and antiquity of its generating apparatus and the expense of operating four distinct stations, foresaw that it must build a single modern and larger steam generating plant or arrange for securing current by means of long-distance transmission through the development of one or more of the water powers within reasonable distance of St. Paul.

Upon investigation it was found that 27 miles east of St. Paul, on Apple River, in the State of Wisconsin, there was a natural fall of about 30 feet. Above the fall a dam could be built to

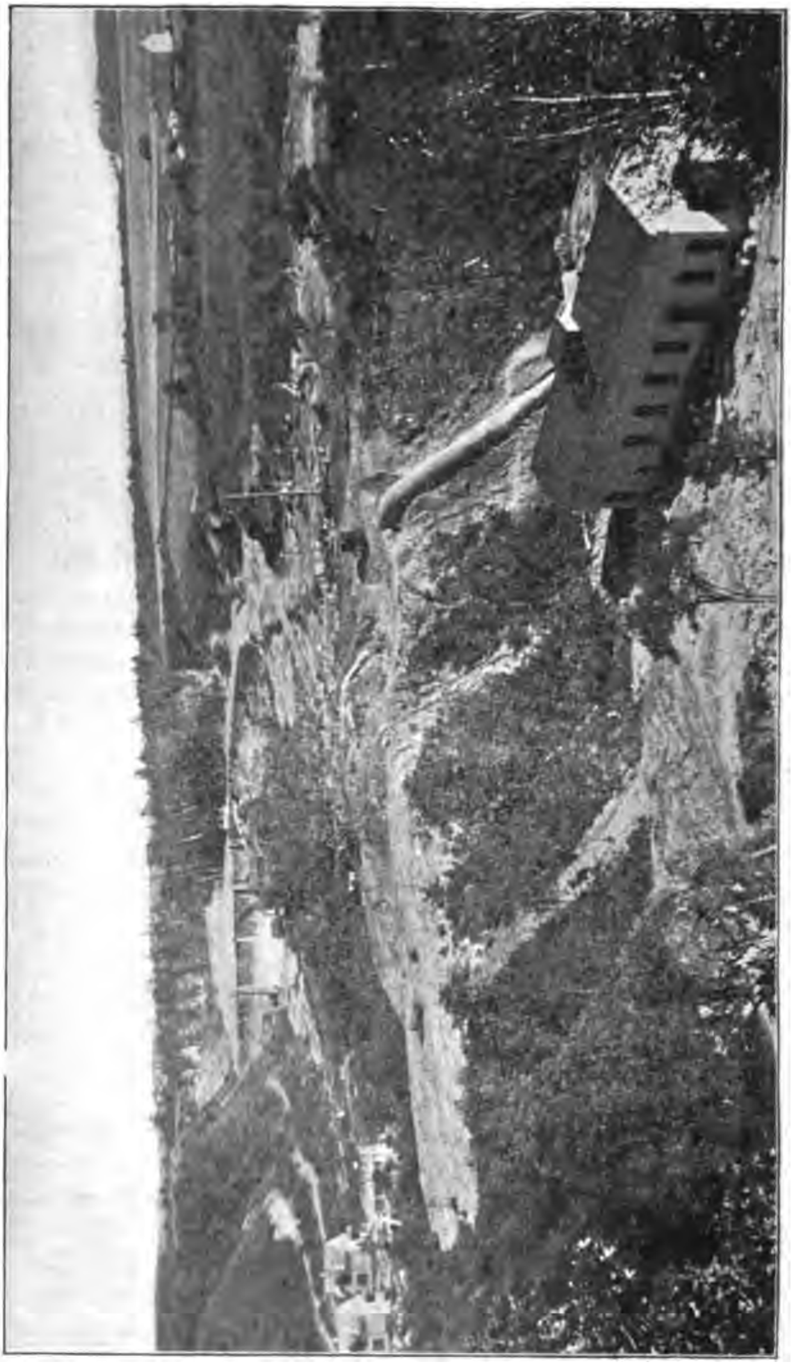


Fig. 1.—General View of Property. St. Croix Power Co.

a height of 47 feet thus affording with a slight drop in the river below the fall a total head of 82 feet. Apple River is fed from innumerable springs and some 25 lakes in north-western Wisconsin and in consequence its discharge is remarkably uniform the year around. With the head afforded, the minimum flow of water in the stream would yield about 2,000 H. P. continuously and during most of the year nearly twice that amount. By the building of a dam, a large reservoir would be formed from which the impounded water could be drawn in any quantity necessary to carry the peak of any load in St. Paul, provided sufficient capacity was installed in water-wheels, generators and transmission line. It was thus demonstrated to the St. Paul Gas Light Company that the power that could be made available at Apple River Falls by a development of the character just outlined, would permit not only the complete shutting down of its four steam plants and avoid the necessity for building a modern

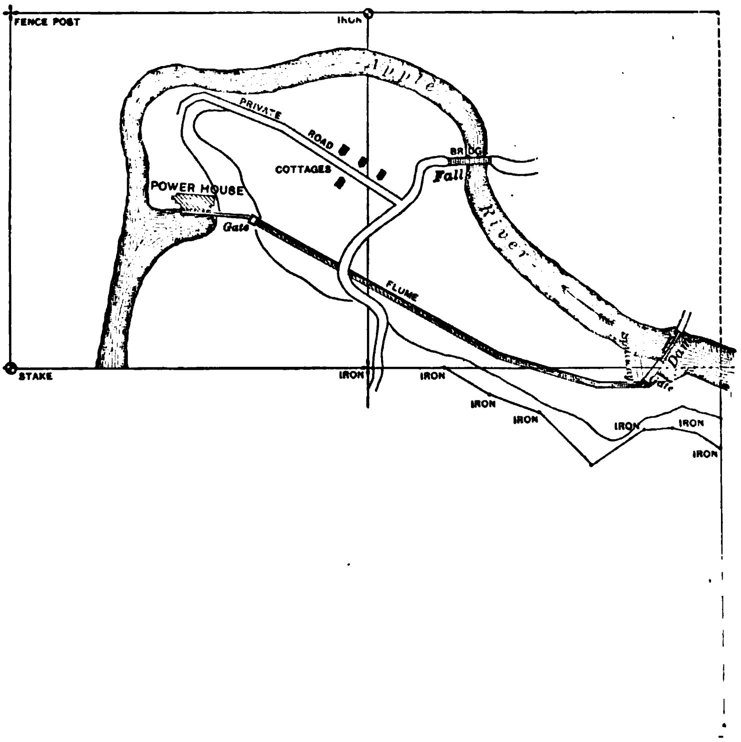


FIG. 2.—Plan of Property.

steam plant but also provide it with nearly twice the salable output of its old stations.

Accordingly, about a year and a half ago, there was organized under the laws of the State of Wisconsin the St. Croix Power Company. This company is friendly to the St. Paul Gas Light Company and to the latter the former contracted to sell all the current it could generate by the development of a power plant at Apple River Falls.

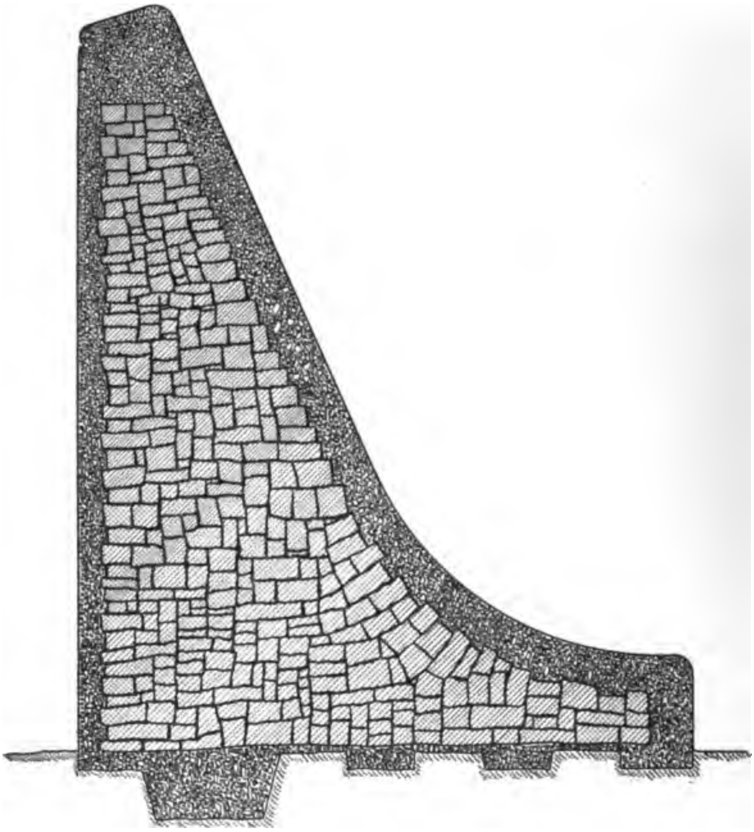


Fig. 3.—Section through Spillway of Dam.

Hydraulic Development.

The accompanying map, Fig. 2, shows the property purchased outright by the power company, and gives a very good idea of the location of the original falls and the present dam, flume and power-house. Above this property only the right to flow such land as would be inundated by the storage reservoir, was acquired

Owing to the inaccessible location of the dam, being about five miles from a railroad station, and the country very rough and hilly, the importation of building stone for the dam was out of the question. The only material available at the falls is a brown sandstone, somewhat harder than the St. Peter rock underlying much of St. Paul and Minneapolis, but not hard enough to withstand constant attrition of the water. It was therefore decided to build the dam with a masonry core, resting on concrete foundations and enclosed in concrete facings.

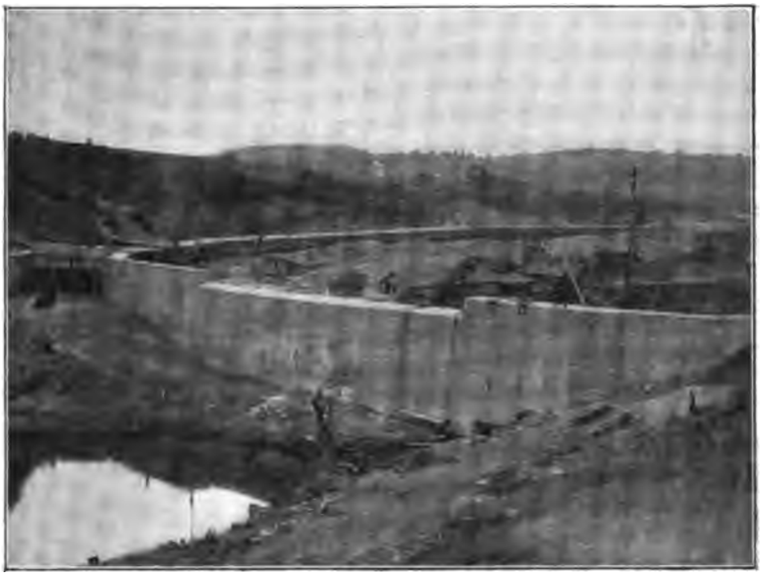


FIG. 4.—The Dam and Flume Looking Down Stream.

The masonry core was not carried higher than within six feet of the crest of the dam, and was built of uncoursed rubble masonry laid in Portland cement mortar, consisting of three parts of sand to one of cement Both the sandstone and unlimited quantities of clean sharp sand were found on the company's property.

The concrete, not only in the dam but forebay, power-house and machinery foundations was composed of one part by measure of Portland cement, three parts of sharp sand mixed with four parts of broken stone. The broken stone was obtained by crushing granite trap or gneiss boulders, commonly called "nigger heads" into cubes not larger than three and a half inches or smaller than one inch; the "nigger heads" being collected from neighboring farms.

Fig. 3 shows the cross-section of the dam through the spillway. It will be noted that the dam is carried down below the level of the bed-rock in the center of the stream to a depth of almost five feet in one broad trench, and that there are three other trenches about a foot deep running entirely across the bed of the stream. The banks of the river which rise twenty-five or thirty feet above the top of the dam are composed of solid sandstone. Into these the dam is carried some twenty-five feet on the north bank and eighteen feet on the south bank. The main seepage trench along the bottom of the dam being carried up and well into both river banks to absolutely cut off any chance for seepage around the ends of the dam. All seepage trenches were filled and all exposed rock covered with concrete before any masonry was laid. The concrete facings on the up and down stream sides and top were, of course, tamped in between the masonry and wooden forms.

FIG. 5.—Dam and Spillway.

The dam is of the arched type, being built as the arc of a circle having a radius of 450 feet. Near the north bank, close to the bed of the river, two steel pipes, each five feet in diameter are built into the concrete work and fitted with gates and crabs to permit control of the water while constructing the dam, or in time of repair, and the regulation of flow over the spillway in case of unusually high water.

At the south end of the dam are the trash racks and near them a sluice for conveniently disposing of the debris and ice.

The length of the spillway is 108 feet, and the total length of the dam 350 feet. There are 3138 cubic yards of concrete and 5025 cubic yards of rubble masonry in the dam.

Incidentally it may be mentioned that when carrying the north end of the dam into the sand rock, a spring was encountered. This was taken care of by laying a pipe for it to discharge through, then building the dam right up and around it.

There has been some controversy as to whether concrete dams are satisfactory, especially in northern latitudes, and the dam here described, although only partially of concrete, will add, I think, another argument in their favor.

It is a pleasure to state that although this dam has experienced extremes of temperature and stresses, it does not show any signs of cracks or leakage, and a number of engineers, experts on this class of work, who have seen the dam since its completion, unanimously agreed that the concrete work is of the highest grade, and that the dam as a whole is a most perfect monolith.

While it it too early to determine the ultimate success of this construction, satisfactory results thus far accomplished are due primarily, I believe, to the following:

First.—All materials in the concrete were of the very best quality. Alsen and Atlas cements were used exclusively, and severe tests made continuously to ensure against deterioration in the grade of cement.

Second.—No concrete was laid and allowed to freeze before setting. The work was started early in September, a year ago, and the autumn was most favorable for outdoor work, which was carried on without interruption until the middle of December, then closed down by cold weather. At that time the north end of the dam had been completed and the south half brought up to within about 18 feet of the top. It stood in this condition throughout the winter and until April 5th, when authority was given the contractor to proceed with the work.

Third.—Although the dam was wholly complete about May 1st, it was allowed to stand almost two months before the waste gates were shut and the water raised to the spillway. This allowed the concrete to thoroughly set and harden before any strains were put upon the dam.

Fourth.—The work was done under constant competent and rigid supervision, with the result that the concrete was of a uniform consistency and mixture, and properly tamped in position.

Flume, Forebay and Penstock.

Although the river bed follows the course shown on the map, the sandstone cliff recedes from the river at a point just below the dam, leaving a less precipitous sand embankment in which the flume has been built as far as the roadway. Beyond the roadway the embankment widens out into a plateau in which the flume is buried. The flume begins at the south end of the dam and with two slight angles runs 1550 feet west, ending in a forebay at the point marked "gate" on the map. From this forebay a steel penstock, 12 feet in diameter, takes its beginning and is used to convey the water down an abrupt embankment to the power-house and tail race 82 feet below.

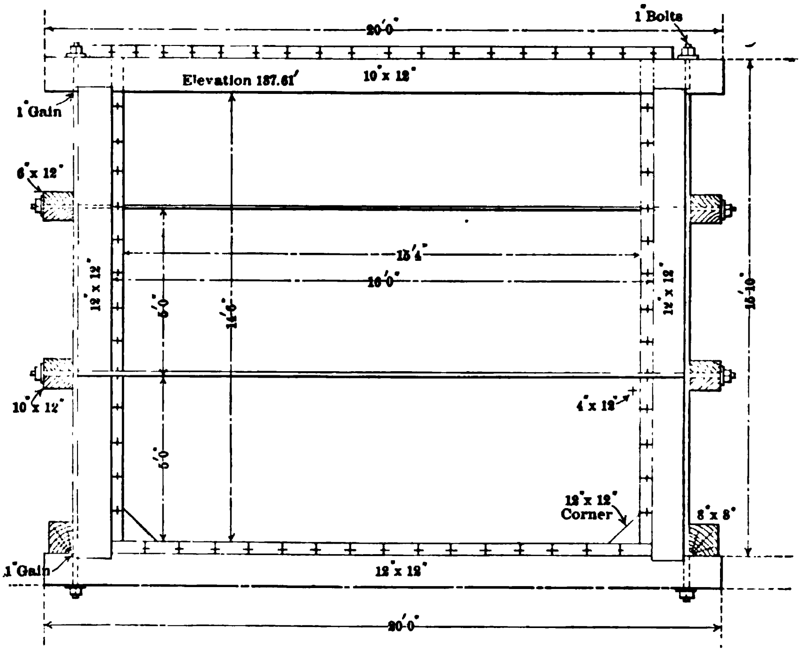


Fig. 6.—Section of Flume.

The flume is constructed entirely of wood, caulked with oakum and braced by both vertical and horizontal tie rods. The bottom stringers are of Oregon fir, which is a superior grade of pine, particularly free from knots and imperfections, found in Washington, Idaho and Oregon and becoming very largely used in the northwest. The remainder of the timber in the flume is Norway pine, except the tongues which are white pine. Fig. No. 6 shows the cross-section of the flume as built, which is of the same dimensions throughout its length. The flume rests on excavated foundations, is level throughout its length, filled on both sides and covered to a depth of two feet with earth.

With a velocity not exceeding three feet per second, it was designed to convey 670 cu. ft. of water per second being sufficient to generate 5000 H. P., under an 82-feet head with wheels having an efficiency of 80%.

The forebay at the lower end of the flume is located about 100 feet back from the brow of the hill. It consists of a rectangular steel box, 24 feet wide, 24 feet long and 17 feet deep and is designed to connect the flume with, and serve as an anchorage for the penstock, and also to afford a place in which to locate gates and racks. The steel box is built of ⅜″ steel, rigidly supported by "I" beams and braces. It rests on a concrete foundation and is supported on all sides by heavy masonry walls, 12 feet thick at the bottom. One of the end walls is pierced by the flume, and the other by the flared mouth of the penstock which is securely riveted to the box and flanged into the supporting wall. Just in front of the forebay and at right angles to and extending ten feet below the bottom of the flume, is a concrete cut-off seepage wall, 42 feet long and three feet thick, designed to prevent the possibility of any water leaking through and following along the sides of the flume and attacking the forebay foundations.

At the head of the flume and close to the dam there is a lateral overflow or waste weir, connected with the side of the flume, and designed to prevent the water in same rising above a predetermined point and putting the top of the flume under pressure. This waste weir is about 27 feet in width and slopes from the side of the flume to the bank of the river. It is designed to automatically prevent any increase in the level of the water in the flume, regardless of how much the water in the reservoir may rise—within reasonable limits—above the spillway. The level of the upper end of the weir where it joins the flume is the same as that of the spillway, but by means of small gates the level of the overflow may be raised to the top of the flume if desired.

In the dam at the head of the flume are three head gates and the iron trash rack previously referred to, while at the lower end of the flume in the forebay are three tail gates with finer trash rack.

The penstock is 12 feet in diameter. It takes its beginning in the forebay and extends in a horizontal direction 88 feet to the brow of the hill, down which it continues 107 feet at an angle of about 45°. Then it turns again and continues in a horizontal direction 118 feet further. The penstock is of open hearth steel plate, $\frac{3}{8}''$ thick above the elevation 140.61 and $\frac{7}{16}''$ below that elevation. The sheets of which the penstock is composed are held together by rivets, spaced $2\frac{1}{2}''$ on centers, all rivet holes being punched $\frac{1}{16}''$ small and reamed out to full size; all joints being caulked and the whole painted with an iron preservative paint. The penstock is supported throughout its length on suitable masonry piers. On the hill-side, the earth has also been tamped under the pipe to give it additional support. The lower

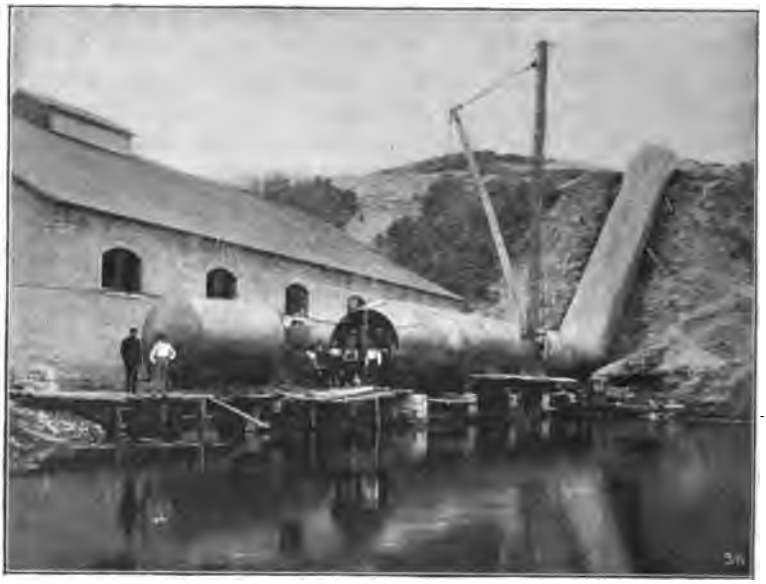


FIG. 7.—12 feet Steel Penstock.

end of the penstock is provided with four branch pipes supplying four main sets of waterwheels, and a smaller fifth branch pipe ending in a " Y " supplies two separate exciter wheels. At the lower end of the penstock is provided a gravity automatic relief valve having a discharge 12″ in diameter. The last section of the penstock is provided with a blank opening for an additional and fifth unit in case it ever becomes desirable to install the same.

GENERATING STATION.

The generating station is a fire proof structure of brick and iron, about 140′ x 50′, divided longitudinally by a partition wall, thus separating the wheel-room from the dynamo-room. (See Fig. 8.)

In the wheel-room are four main sets of waterwheels, space being reserved for the fifth unit which may be added later. Each set consists of two 36″ special "Victor" wheels, mounted horizontally in a nine feet cylindrical steel wheel-chest from which they discharge through a six feet draft tube, eight feet long. Each pair of wheels is, of course, on a single shaft which extends through the end of the wheel-chest built into the partition wall, and is direct connected to a 750 K. W. generator, Each wheel-chest is supplied from the penstock by its own feeder pipe in which is located a 56″ gate-valve operated from a shaft driven by a 7½ H. P. electric motor. Each wheel-chest is surmounted by an automatic spring relief valve having an opening 12″ in diameter. There are two exciter wheels, each direct connected to a 30 K. W. direct current generator. The exciter wheels have their own branch feeder pipes, wheel-chests and separate gate-valves.

The waterwheel governors are of an improved type of the Giesler pattern. They are guaranteed to maintain the speed within 3% of normal for any instantaneous change in load not exceeding 25% of the load at the moment of variation. The governors are electrically controlled, being operated by the 125-volt exciter current.

All the alternators are 750-K.W., three-phase, 800-volt, 60-cycle revolving armature, separately excited machines, running at 300 r. p. m. They will carry full load continuously without heating more than 40° C. above the temperature of the surrounding air, and have an inherent regulation slightly under 5% on non-inductive load.

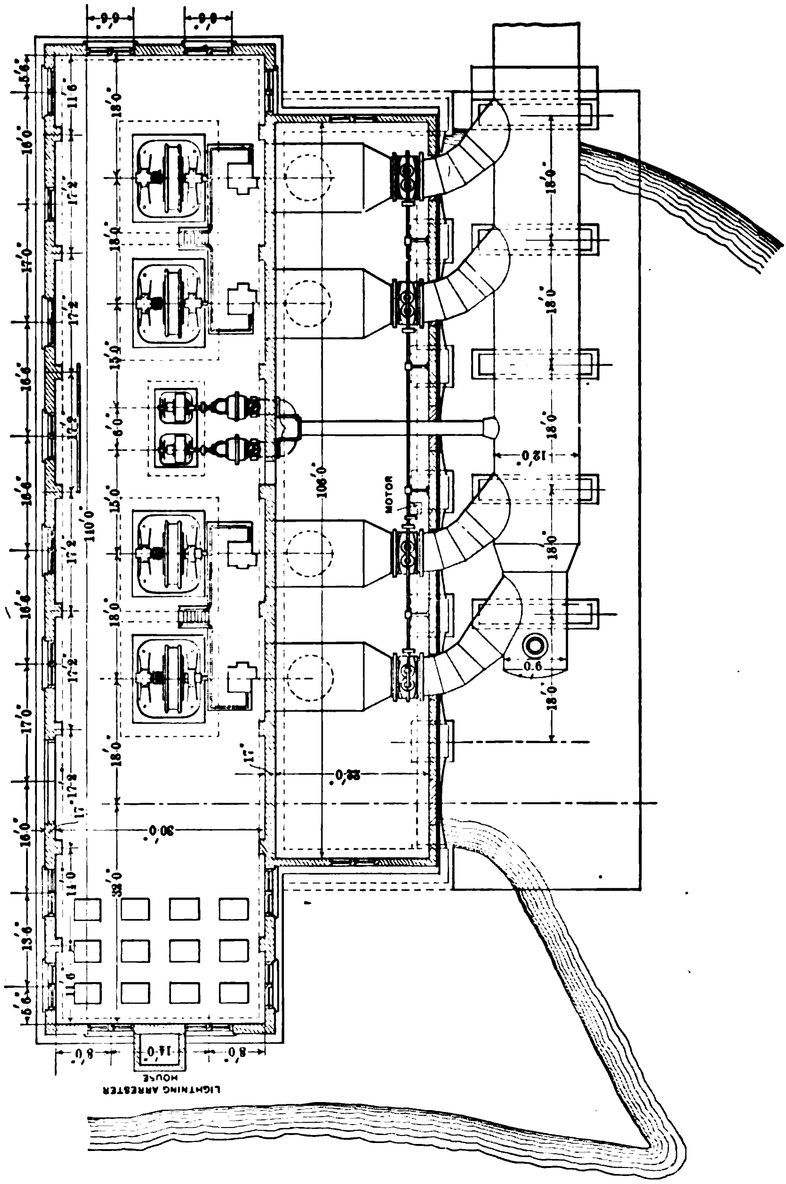


FIG. 8.—Plan of Generating Station.

The direct-current exciters are shunt wound, operating at 925 r. p. m., and each machine is of sufficient capacity to excite five 750-K. w. alternators.

Across the lower end of the dynamo-room is the marble switchboard consisting of an exciter panel, four generator panels, two transformer panels, and a local service panel. The exciter panel is supplied with the usual instruments, but the alternator panels are each equipped with one main oil switch, in series with two triple-pole quick-break jaw switches, for throwing the machine onto either two sets of 'bus-bars. At the top of the panel is an ammeter, an indicating wattmeter, and a field ammeter with the usual synchronizing lamp, field-switch and voltmeter plug. The transformer panels will each be provided with an induction recording wattmeter, a single three-phase oil switch of special design, having a capacity of 1500 K. W. at 800 volts, and a potential indicator which enables operators at the generating station switchboard to determine the voltage at the St. Paul sub-station, regardless of the power factor of the load or the drop in the line.

A brief description of this type of potential indicator may not be amiss. Across the terminals of the main transformer leads is connected a small transformer supplying in its secondary circuit, an E. M. F. in step with, and proportional to that of the generator. In series with the main transformer leads is a small series transformer which supplies in its secondary circuit a current always in step with, and proportional to its primary current. The secondaries of the two transformers are connected in series through an inductive resistance and an ohmic resistance. Both the inductive resistance or reactance and the ohmic resistance are so adjusted that for a given current through them, their respective E. M. F.'s have the same value relative to the E. M. F. of the potential transformer as the reactance and resistance E. M. F.'s of the transmission circuit have to the E. M. F. of the generator. Therefore, the local reactance and resistance E. M. F.'s reduce the E. M. F. supplied by the potential transformer to a potential indicator connected in this local circuit, in the same proportion as the line reactance and resistance E. M. F.'s cut down the generator voltage, and thus the potential indicator at the generating station is made to indicate the voltage at the point of distribution.

The local service switchboard panel is equipped with switches for controlling the electric heaters by which the power-house is warmed, also the incandescent and arc lighting circuits and the motors driving the blowers.

There have been installed six air-blast transformers of 500 K.W. capacity each, which step the voltage up directly from 800 to 25,000 volts. As operated, the transformers are connected in two sets of three each with "Y" connections. The low-tension side of each set of transformers is joined directly with the transformer panel switches, and the high-tension side with Westinghouse "spider" switches, through the use of which either bank of transformers may be connected to either or both of the transformer circuits.

All the electrical apparatus in the power plant was furnished by the General Electric Company, except the high-tension switches and the alternating current arc lamps, which latter were purchased from the Manhattan General Construction Company. These lamps are of the enclosed type and require 6.6 amperes. They are operated in series directly from the 800-volt 'bus-bars, there being eight lamps and regulator in each circuit.

A 20-ton hand crane traveling the entire length of the dynamo-room, affords a convenient method for handling the heavy machinery.

TWENTY-FIVE THOUSAND VOLT OVERHEAD AND UNDERGROUND TRANSMISSION LINE.

Two three-wire, three-phase transmission circuits, each consisting of 24½ miles of overhead bare copper wires and three miles of underground cables connect the generating plant with the distributing station in St. Paul.

Both overhead circuits are carried on a single line of poles. The wires of each circuit are on one side of the poles and are supported so as to be at the verticles of an equilateral triangle, having 24″ sides. The conductors are of No. 2, B. and S. medium hard-drawn copper wire, carried on glass insulators of the "Provo type"—the same as those used on the 40,000-volt transmission in Utah. The insulators are 7″ in diameter and have a triple petticoat. They are mounted on special locust pins boiled in paraffine, carried on two 4″ x 5″ Oregon fir cross-arms. The poles are mainly of Oregon fir and are spaced not more than 110 feet apart. No poles less than 30 feet in length and eight inches in diameter at the top are used. Poles of minimum length are planted 5½ feet in the ground and six inches deeper for every additional five feet in their length. The line was designed to be practically level, irrespective of configurations in the earth's surface. The corners and angles in the line are reduced to as few as possible, consistent with securing a right-of-way at a reasonabl price; no angle in a conductor at any insulator is less than 165°

thus avoiding any dangerous tendency to break the pins. In making a right angle turn special construction is used (see Fig. 9) affording seven points of support for each wire. For slight turns two or three poles as may be required, are set ten feet apart but no more than one insulator per wire is allowed on a single pole.

The transmission line really takes its beginning at the terminals of the step-up transformers in the dynamo-room of the generating station, whence it passes through the Westinghouse high-tension switches into a brick lightning arrester house abutting against the end of the power-house. Here are located choke coils and lightning arresters. From the arrester house the wires pass out through circular openings in the wall which are sheltered by a gabled roof and run thence in a general westerly direction to a similar arrester house in the city of St. Paul, where they terminate in the heads of the underground cables.

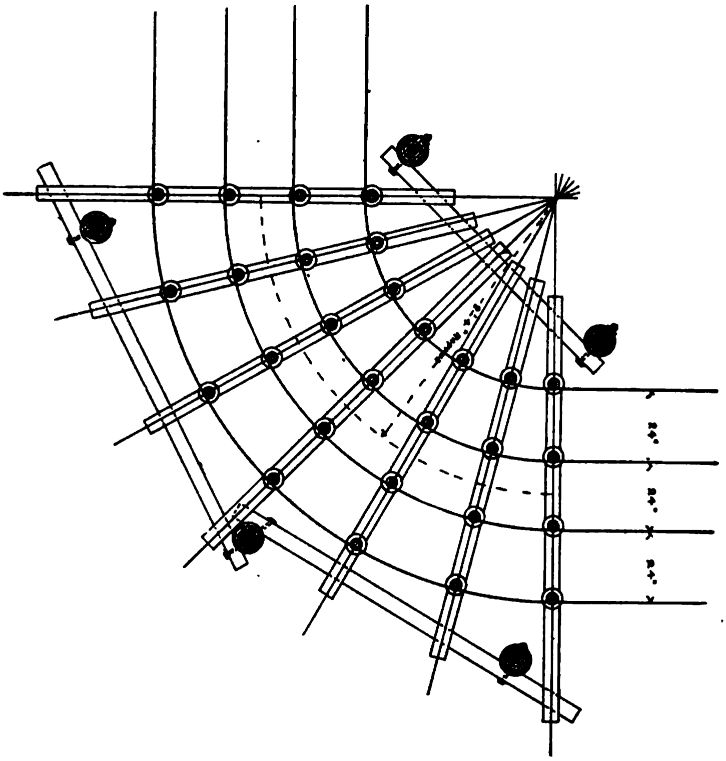


Fig. 9.—Special Corner Construction.

No especial engineering difficulties were met with in the construction of the aerial line, except in crossing the St. Croix river which is about a half mile wide, with precipitous banks 100 or more feet in height. Advantage was taken of a bridge built by the Wisconsin Central Railway, and long oak pieces were fitted between the ties every 50 feet throughout the length of the bridge. These oak pieces project about 20 feet beyond the edge of the bridge and on them the six wires are carried in a horizontal plane. To nullify any bad effects of the iron work in the bridge, the wires of each circuit are spiraled three times in the length of the bridge.

As is usual with two parallel three-phase circuits, one circuit is spiraled twice relatively to the other circuit, in addition to the transpositions on the bridge, to prevent mutual induction.

Six feet below the power transmission circuit, on a separate cross-arm are carried two No. 10 galvanized iron wires, which constitute the telephone line. The wires are transposed at every fifth pole, which very satisfactorily prevents any inductive effects in the line and results in very efficient telephone service.

There are two three-conductor lead-covered cables connecting the lightning arrester house with the distributing sub-station located on Cedar street in the very center of the business section of St. Paul. These cables are in four-hole McRoy vitrified clay conduits laid in concrete. The conduits follow the grade of the streets except where it was necessary to pass under a number of railroad tracks in a deep cut. Here, the conduits end in the top of a brick well about fifty feet in depth, down which the cables drop passing from the bottom of the well in other conduits to another well on the opposite side of the tracks through which they rise again to the conduits laid below the pavements of the street.

In considering the use of cables for 25,000-volt transmission under ground, the writer found that a number of reputable manufacturers not only declined to bid on his specifications, but would not entertain any proposition for furnishing such cables, even under their own specifications. There were only two companies that were anxious to undertake the work and accordingly a contract was entered into with these companies, one to furnish a rubber insulated and the other a paper insulated cable.

The specifications provided that the general design of both cables should be the same, that is, each conductor having an area not less than 66,000 cm., is composed of seven strands of copper wire, enclosed in insulation, the three laid up in jute and the whole enclosed in a jacket of the same insulating material as that used about each conductor. Outside of the jacket is the lead sheathing $\frac{1}{8}''$ in thickness, making the cable complete about $2\frac{1}{4}''$ in diameter.

The "National" cable is insulated with paper treated with a secret compound. The insulation about each conductor is $\frac{9}{32}''$ in thickness. That of the enveloping jacket, $\frac{4}{32}''$ thick. The covering of this cable is of lead protected on the exterior by a coating of tin.

The insulation of the "Safety" cable is about a 35% compound of the best "old up river" Para rubber $\frac{7}{32}''$ thick around each conductor, wrapped with a drilled tape served with jute, with the jacket $\frac{5}{32}''$ thick. The sheathing of this cable is of lead, mixed with 3% of tin.

The contracts entered into with the above companies for cables included not only their manufacturing the cables and testing them to 40,000 volts in their factories before shipment, but also the installation of the cables complete ready for operation in the conduits in St. Paul. The contracts further include a guarantee for a period of five years protecting the purchaser against any breakdown in the cables, except those due to extraneous and mechanical injuries, and further permitting at any time during that period, the testing of the cables *in situ*, up to a potential of 30,000 volts. The writer's aim in having the contract for each cable awarded to a separate company was to secure the benefits of competition, in promptness of delivery and perfection of manufacture. Furthermore, as underground work of such tension had never been attempted before, there was some question as to whether rubber or paper would prove the more durable insulator under these conditions.

While of course,the ultimate success of 25,000-volt underground transmission can only be determined by the lapse of time, and the action of high voltage in its effect on the insulation, nevertheless the success in operating seems to have demonstrated the wisdom of the experiment and great credit must be given to the manufacturing companies for their co-operation in undertaking what had never before been attempted and what many manufacturers prophesied would result in failure.

The calculated resistance of each conductor between the generating and distributing stations is 23. ohms. The drop in voltage between the same points, for 3,000 K. W. delivered with a 90%

power factor, and 25,000 volts initial potential, figures 7.7% operating both lines in multiple which will be the usual practice.

SUB-STATION AND APPARATUS.

The distributing station in St. Paul is an iron and brick building designed to contain the necessary apparatus for reducing the potential and controlling and transforming the energy received over the transmission line, for distribution in the City of St. Paul. The building is 50′ x 65′, two and a half stories in height. One-half of the building has a basement divided into two rooms, one, in which all the static step-down transformers and high-tension switches are located, is connected by a tunnel with the street conduits; the other serves as a toilet room and place in which to locate the apparatus for heating the station. (See Fig. 10.) The main floor is divided into three rooms, open to the roof. The larger room, 50′ x 50′, contains six 250 K. W. rotary converters and two marble switchboards, extending along two sides of the room. The second room on this floor serves as a hallway to the main room, and affords a place in which to locate telephone box, etc. The third room is open from the roof to the basement but is entirely cut off and separated from all the rest of the building, except for a single door from the hallway. This room is intended for a storage battery, which it is planned to install later.

Each conductor of two high-tension cables passing through the tunnel into the transformer room, ends in one terminal of a single-pole knife switch, to be operated only when current is off the line and installed to permit convenient testing of cables, etc. The other terminal of each switch is connected to a high-tension 'bus-bar, from which taps are taken off to the high-tension switches controlling the circuits to the different sets of transformers. The ends of the cables are also connected to static dischargers, which are merely a number of standard lightning arresters, connected in series.

The high-tension 'bus-bars and their taps to the high-tension switches and from the switches to the transformers, are single conductors insulated with ¼″ of best Para compound, and guaranteed to withstand 25,000 volts continuously. The conductors are carried in conduits made of wood pulp indurated with asphaltum, manufactured by the Fibre Conduit Company. The conduits are guaranteed to withstand 20,000 volts without breaking down.

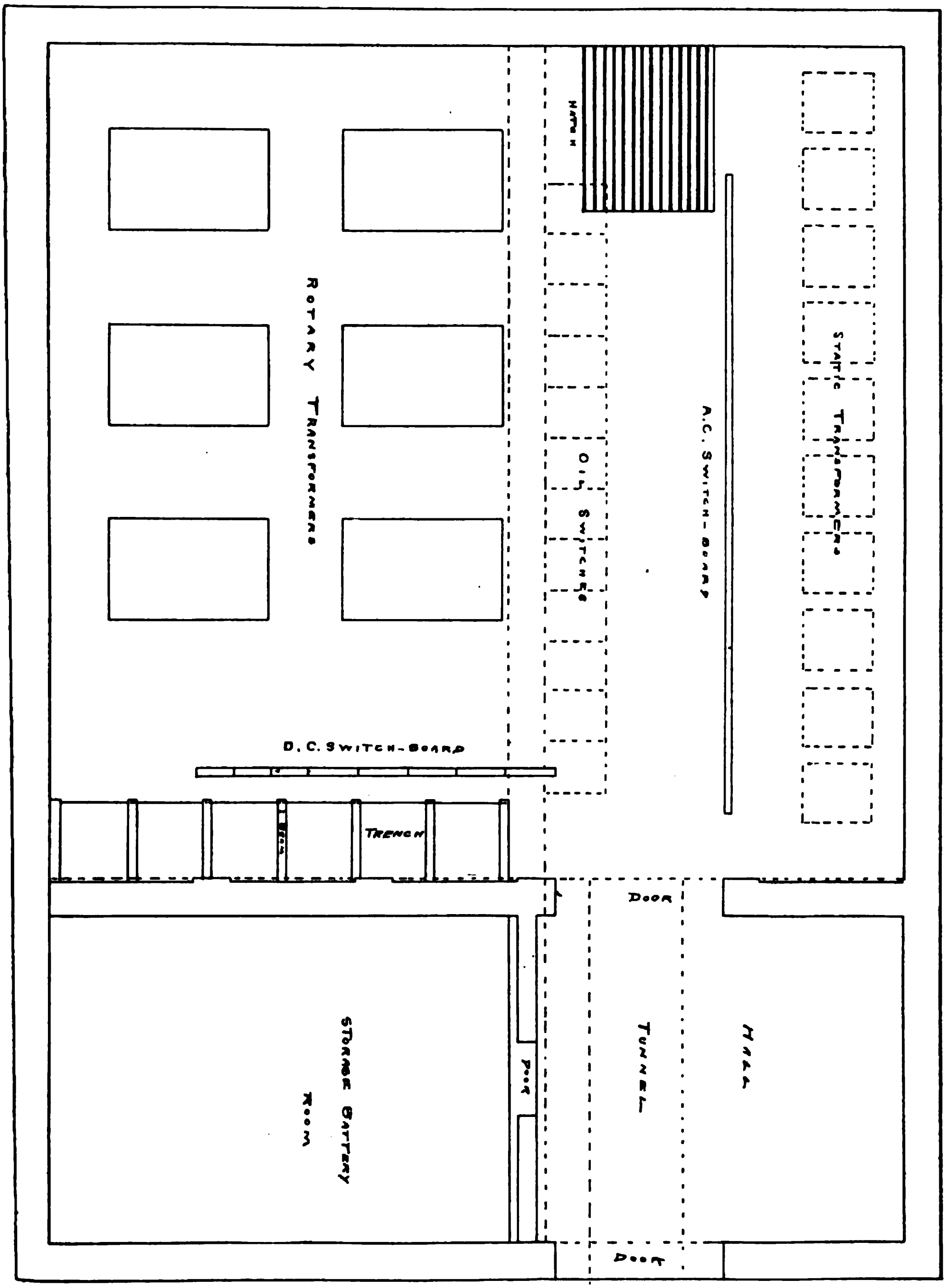


Fig. 10—Transformer Sub-station.

The high-tension oil switches are of the single-pole three-break type, operating under oil and designed to break 25,000 volts and 50 amperes. The switches are closed by hand but opened by the releasing of a latch controlled by a local circuit from the main switchboard up-stairs. There are 24 high-tension switches in all —12 connected with each set of the cable 'bus-bars. As all high-tension work is three-phase, this necessitates the closing of three switches to connect any set of transformers with either set of 'bus-bars. (See diagram connections Fig. 11.)

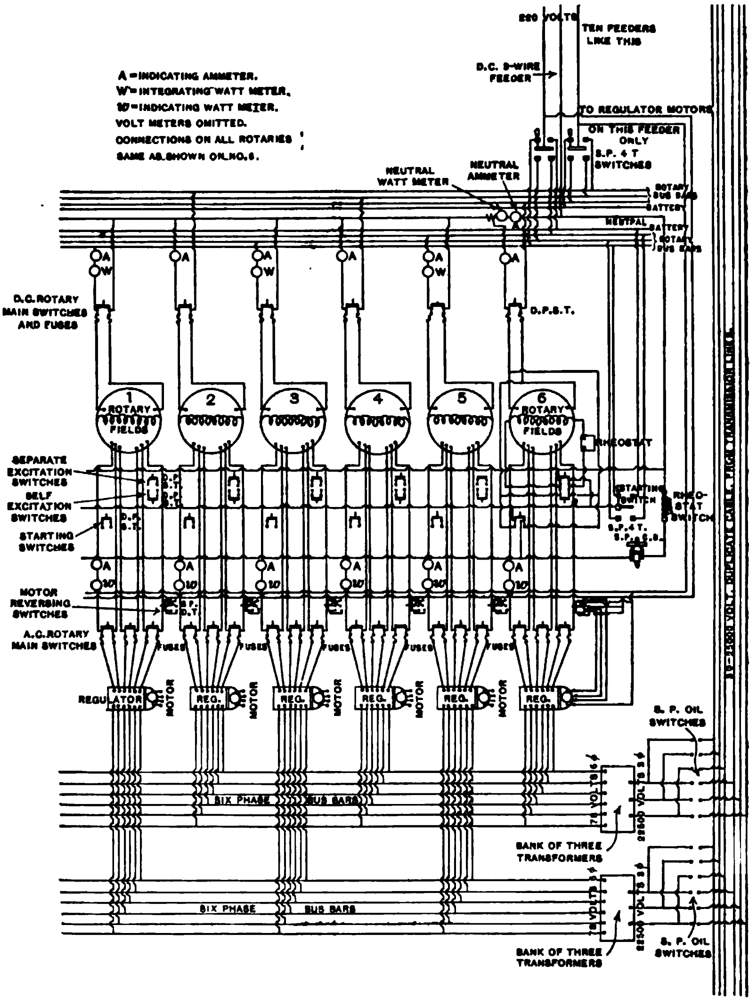


FIG. 11—Wiring Diagram for 6-Phase Apparatus and Rotary Converters.

There are four banks of static step-down transformers—two banks consisting of three 22,500 to 78-volt oil-cooled 300 K. W. three-phase to six-phase transformers and two banks of two 22,500 to 2,100–2,700-volt oil-cooled 200 K. W. three-phase to two-phase transformers.

Each one of the 300 K. W. transformers has a single winding on the primary, and two entirely distinct and separate windings on the secondary. By connecting three of these transformers in a set, the three-phase to six-phase transformation is effected. One set of these transformers supplies current to the rotary converters, operating between the positive and neutral wires, and the other set to those rotaries operating between the neutral and negative wires of the Edison three-wire system of distribution throughout the city. There is kept on hand a spare transformer in case of break-down, but as all transformers in the sub-station are connected in delta, it is perfectly feasible to successfully operate, although there are but two transformers of a set connected in circuit. In fact, this was the method of operating for the first few weeks after starting the plant and until the remainder of the transformers were received.

The two identical sets of three-phase to two-phase 200 K. W. transformers provide for the alternating current distribution throughout the city. On the front of each transformer case is mounted a quick-break multipoint switch connected with leads brought out from the secondary windings of the transformers. The movement of the switch throws more or less turns of the secondary in circuit and thus adjusts the potential in steps of 21 volts to any desired point between 2,100 and 2,700 volts.

The plan of operating from the generating station is to maintain irrespective of load or line loss, the potential on the high-tension 'bus-bars in the sub-station at 22,500 volts, as shown by the potential indicators previously described. This potential gives 78 volts for the rotary converters which potential may be varied seven volts either up or down, by use of inductor regulators of which there is one for each rotary. In a similar manner the potential for alternating current distribution is regulated by the setting of the multipoint switches at any point between 2,100 and 2,700 volts, depending on the load.

The use of six-phase transformers and converters is novel. The reason for the adoption of six-phases instead of three-phases was to secure the advantages of reduction of copper losses in the ar-

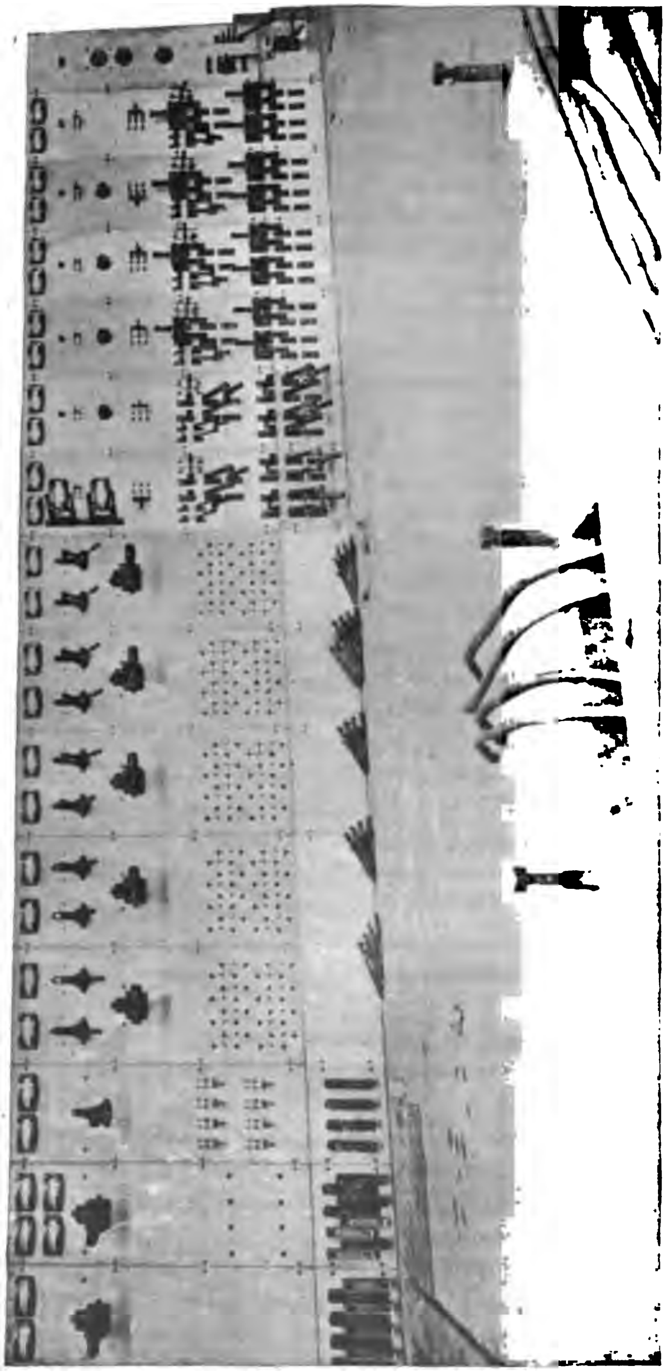


Fig. 12—Switchboard, Cedar Street Edison Station.

mature, and the accompanying reduction of temperature and its better distribution. At first sight it might seem that the increased complexity involved in the use of six-phases would not counterbalance the advantages to be gained. Practically, however, the use of six rings and the necessary additional taps to the windings on the armatures amounts to nothing in the operation of the machines. The dividing of the secondary windings on the transformers for two independent circuits results in no complication or expense. On account of the large current, the use of six conductors between the transformers and switchboard and between the switchboard and rotaries, was necessary whether three-phase or six-phase machines were installed. The switchboard is practically the same for either number of phases, except that the number of main switches was increased from two to three. This disadvantage, however, may be disregarded when a decided increase in the capacity of the rotaries is secured. The rotaries are ordinarily started from the direct-current end but are equipped with break-down field switches and designed for starting from the A. C. end where necessary.

Fig. 12 illustrates the alternating current switchboard, which is about 35 feet in length and eight feet in height.

On the extreme left is a relay panel through which current is usually distributed by means of four-conductor cables to one of the old steam generating plants. This plant will be used as a relay station and in case of a break-down in the water power transmission plant, current will be supplied from it to the sub-station. The second panel from the left is a transformer panel connecting either set of the static transformers supplying current for alternating current distribution to either of the two sets of four 'busbars. Each two-phase circuit is provided with two Stanley recording wattmeters (not shown), two ammeters, two recording wattmeters, a four-pole oil switch and fuses.

The panel next adjacent on the right controls the power distributing two-phase circuit. On this panel are also eight small double pole switches each of which controls the current to the magnets releasing the latches of three of the 25,000-volt switches. The five following panels each control two single-phase alternating current lighting circuits. Each of these panels is provided with an ammeter, automatic oil circuit breaker and oil switch in series with plug switches. There will be noticed a number of holes in these panels which are designed for the plug switches, permitting the plugging of any single-phase feeder onto any pair of the eight 'bus-bars. The double-pole plugs used are shown in the illustration lying in a pile at the foot of these panels.

Next come six alternating current rotary panels supplying current at 78 volts to the alternating current end of the rotary converters. These panels are provided with three two-pole switches for the six-phase circuit, also indicating wattmeter and main ammeter, thus giving an indication of the power factor of the load. There is also the handle of the field rheostat, a direct current starting switch, double-pole, double-throw field-switch, synchronizing plug and lamp and a small direct current two-pole, double-throw switch controlling the motor actuating the six-phase inductor regulators. The inductor regulators are placed on the floor directly behind the A. C. rotary panels.

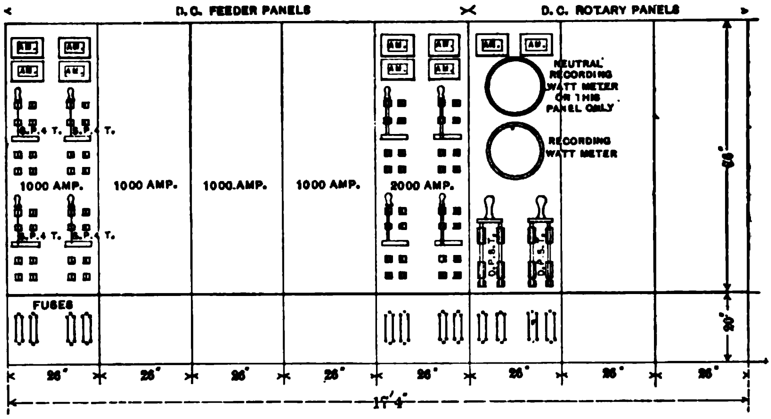


Fig. 18—Direct Current Switchboard.

The extreme right hand panel contains a double-throw direct current switch, a starting rheostat switch and an automatic circuit breaker, through which is supplied and controlled the direct current from the Edison system used in separately exciting and starting the rotary converters. On this panel there are also three multipoint voltmeter switches, through the use of one of which the voltage of any of the Edison feeders or rotary converter 'bus-bars at the other switchboard (See Fig. 13) may be shown on the direct current voltmeters hinged on the right of the board (not shown in the illustration Fig. 12.) The other two voltmeter switches in conjunction with the swinging alternating current voltmeters shown on the left of the A. C. rotary panels permit the reading of the potential of any of the alternating current feeders or alternating current end of the rotary converters.

The direct current three-wire switchboard, about 18 feet long and eight feet high, (Fig. 13) is at right angles to the board just described. It consists of eight panels, three for the direct current end of the rotaries and the remainder for the feeders of the Edison three-wire distributing system.

Each direct current rotary panel controls the current from a pair of rotaries operating together on the three-wire system.

The Edison feeder panels are provided with single pole, four-way switches of special design which permit the throwing of any feeder on any one of four sets of 'bus-bars. Three of the 'bus-bars may be supplied at different potentials from each of the three pairs of rotaries. The fourth set of 'bus-bars is designed for use in connection with the storage battery, when same shall be installed. It will thus be seen that great flexibility in distributing potential is attainable, for, if necessary, the battery can be used independently of the rotaries, making a fourth and independent voltage available for feeder service. The illustrated diagram of the direct current switchboard shows the instruments and their arrangement sufficiently clearly to render their enumeration unnecessary.

The static transformers and rotary converters were furnished by the General Electric Company. The General Incandescent Arc Light Company furnished the high-tension switches and both switchboards, the latter being equipped with indicating instruments mainly manufactured by the Wagner Electric Manufacturing Company.

TESTS.

A report of the tests of the hydraulic and electrical apparatus might prove commonplace, but the following relating to the overhead transmission line and underground cables may be of interest because little data has been published with regard to the charging current of overhead lines and nothing whatever, as far as the writer is aware, regarding high-tension cables.

The first tests made were simply to ascertain whether the cables could carry the voltage under which they were to operate. The paper cable was first tested, the voltage being gradually raised to 30,400 volts. This was on the afternoon of October 14th, which I believe, marks the date of any attempt to carry such high potential underground in connection with any commercial plant. The rubber cable was successfully tested about two weeks later in the same way.

In making measurements and in the following data on the charging current of overhead lines and cables, no allowance is made for any leakage current, as exhaustive and careful tests made on high-tension lines at Telluride by Mr. R. D. Mershon prove that with proper insulators, with no precipitation and with the voltages here used, any leakage current is inappreciable.

The charging current was measured by placing in the high potential circuit, a Stanley hot-wire ammeter reading from zero to thirteen amperes. The Stanley meter was compared with a Weston portable ammeter reading from zero to 15 amperes, which had just been calibrated at the Weston laboratory. The difference in readings between the two ammeters was small, but corrected readings are given in the accompanying curves. The voltage readings were taken by a newly calibrated Weston portable voltmeter connected to the secondary of a small transformer, having a ratio of one to two-hundred and designed and built especially for voltmeter measurements by the Pittsburg Transformer Company. The voltmeter used was compared during the tests with another portable Weston voltmeter with which it agreed closely. It was also compared with a General Electric switchboard voltmeter and the practical correctness of the instrument used was verified.

The alternations of the generators supplying current for the charging tests were kept constant by maintaining the speed constant as shown by a tachometer. No measurements were made as to the wave forms of the generators.

In making all charging current measurements, only two generators were used. For supplying the current at the generating station, where most of the tests were made, one of the 300-revolution General Electric generators there installed, was employed, which by reason of the source of its power, could easily be kept at a uniform speed. At St. Paul, a Westinghouse revolving armature 400-revolution 375 K. W. 60-cycle machine was used.

Fig. 14 gives the curves as plotted from the actual measurements of the charging current to one of the three-conductor overhead lines, also to two of the three conductors also to the three-conductor line connected to the paper cable, also two three-conductor overhead lines connected one to the paper cable and the other to the rubber cable, both circuits being in multiple with one another, and supplied with three-phase current. The four above measurements were made from the generating station. There is also shown a curve for the paper cable as measured from the St. Paul end by the Westinghouse generator.

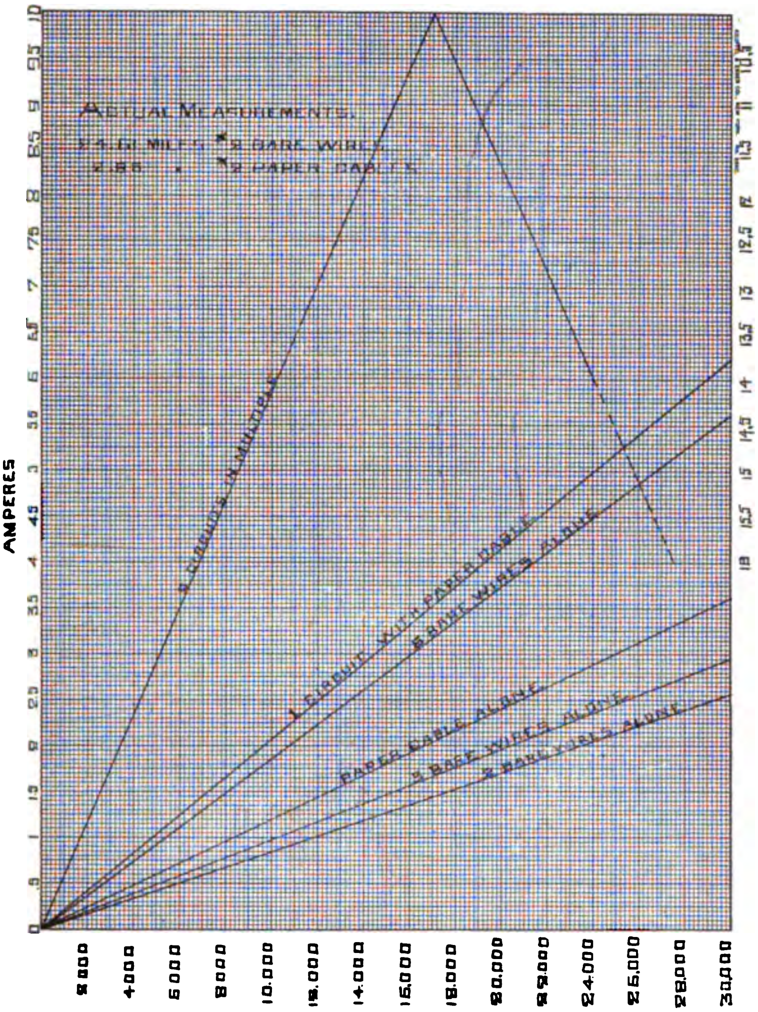


FIG. 14.

Measurements on both overhead lines showed that the charging current to either line was practically the same as that to the other. Furthermore, it was found that the charging current to one line was practically the same whether both ends of the other line were left disconnected from everything, or whether its three conductors were tied together and connected to good ground.

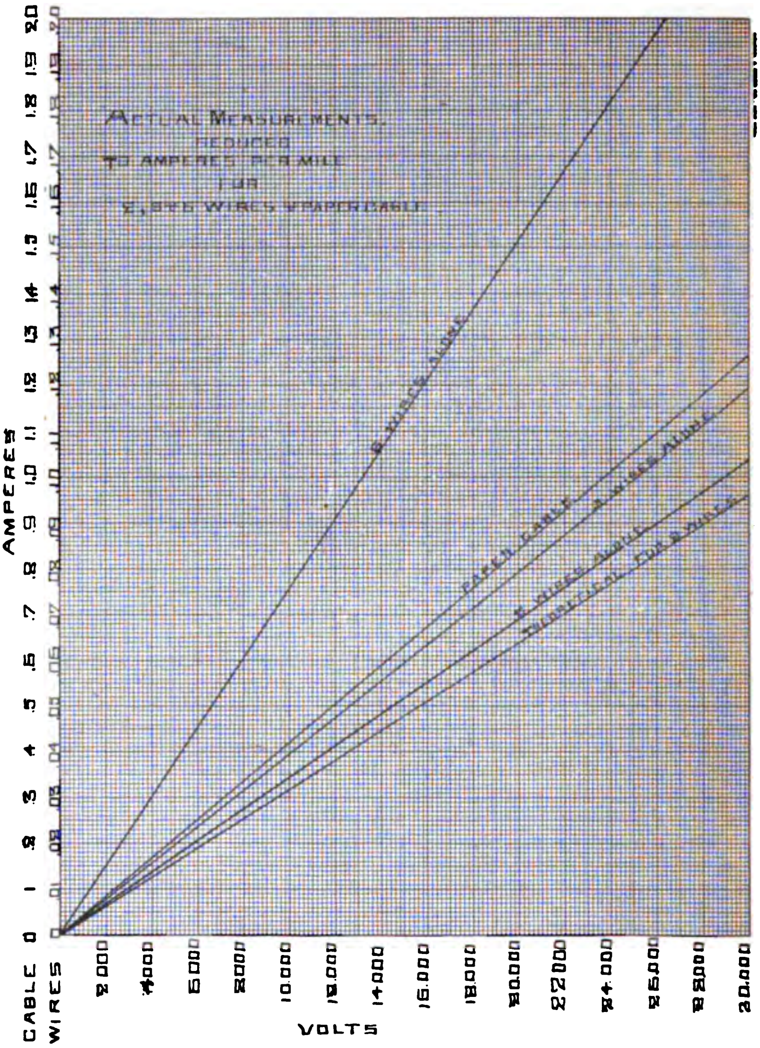


FIG 15

Fig. 15 shows the charging current as measured, reduced to amperes per mile for two, three and six wires (the latter being two three-phase circuits in multiple) and also for the paper cable. From some few measurements the charging current for the rubber cable was found to be a little more than double that of the paper cable. This result from the standpoint of overcoming the reactance in the circuit, would make the use of a rubber cable the most desirable. It will be noticed that the charging current for two wires of the three-phase circuit is appreciably less than when voltage is applied to all three conductors. It checks very closely with what would be expected as figured. There is also shown a dotted line indicating the charging current as plotted from the formula for capacity between two wires. Lack of agreement between the theoretical and measured curves is no doubt mainly due to the departure of the generator wave from that of a true sine curve.

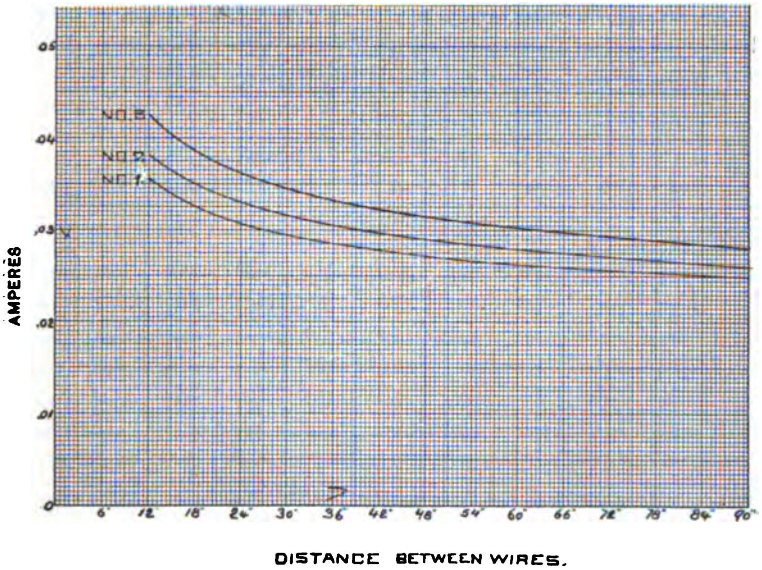


FIG. 16.—Variations in Charging Current due to Separation of Wires.
No. 1 No. 4 Wire.
No. 2 No. 1 "
No. 3 No. 0000 "
10,000 Volts.

Fig. 16 shows the charging current per mile per pair of wires at 10,000 volts, 60 cycles, for Nos. 4, 1 and 0000 conductors with the wires separated from 12 to 84 inches.

These curves were drawn in determining the advisable distance at which to space the conductors, and are here given as illustrating the comparatively small advantage to be gained in the way of reducing the charging current by separating the conductors, after a distance of about three and a half or four feet between wires is reached.

The following data on charging current taken from the writer's note book may be convenient for reference, and is therefore here included because it has never before been published.

CALCULATED CHARGING CURRENT.

Two parallel wires: Length one mile: 10,000 volts:
Sine wave: Sixty cycles:

The current varies directly as the length of the line, the voltage and the cycles, so that the current for any given line and different voltage or cycles may be easily calculated:

Distance between centers of wires.	Size of Wire—B. & S. Gauge.									
	6	5	4	3	2	1	0	2/0	3/0	4/0
	Amperes at 60 cycles.									
18"	.0313	.0317	.0324	.0332	.0339	.0351	.0358	.0366	.0373	.0386
24"	.0295	.0302	.0308	.0315	.0322	.033	.0337	.0344	.0354	.0362
30"	.0285	.0290	.0297	.0302	.0308	.0316	.0323	.0330	.0338	.0346
36"	.0276	.0281	.0287	.0293	.0299	.0305	.0312	.0319	.0326	.0333
42"	.0269	.0274	.028	.0285	.0291	.0296	.0303	.031	.0316	.0324
60"	.0255	.0260	.0264	.0269	.0274	.0280	.0285	.0291	.0298	.0303

It is a pleasure to state that we have never had any trouble with resonance, harmonics or any other of those "bogies" which have proved in some instances destructive to apparatus and are a cause of disquietude to the engineer of almost any long distance transmission plant, until after the same has been put into successful operation.

This paper would be incomplete without acknowledging the credit due to the writer's associate, Professor R. C. Carpenter, of Cornell University, for his assistance and co-operation in designing the mechanical and hydraulic plant. Much praise should also be given Mr. L. W. Rundlett, our resident inspector and engineer on the mechanical and hydraulic work, through whose experience, patience and faithfulness, the results of the excellent concrete work were attained. Mention must also be made of Mr. J. L. Harper, who acted as our resident inspector on the transmission line and electrical work, and who is now serving as the General Superintendent of the operating station at Apple River Falls. Mr. William De la Barre, of Minneapolis, advised with us from his wide experience in hydraulic matters, and Mr. W. A. Gordon, of our own office, has materially assisted in calculations and tabulations. Messrs. H. J. Gille and Fred R. Cutcheon, superintendent and engineer, respectively, of the electrical department of the St. Paul Gas Light Company, and Mr. H. L. Doherty, president of the Denver Gas and Electric Company, had much to do with the design of the sub-station switchboards. It should be stated that Mr. Doherty was the first engineer to recognize and appreciate the possibilities for the power development in Wisconsin and its transmission into St. Paul, Minnesota.

DISCUSSION.

MR. FLOY :—I would like to add a few remarks to what has been said in regard to these curves of charging current. There was a tendency shown, from the points as plotted, for the curves to sag below zero at the lower end. The instruments that were used being designed especially for high voltage and large current readings did not read closely below 10,000 volts with the voltmeter, or 1 or 1½ amperes, with the ammeter. The result was that we could not get any satisfactory readings down at the lower end of the curves, although some curves, as I have stated, showed a tendency to sag at the lower end. To-day I received a letter from Mr. Edward P. Burch, of Minneapolis, who was formerly superintendent of the Twin Cities Street Railway. Mr. Burch took some measurements on paper cables furnished by the National company for supplying current from Minneapolis to St. Paul in connection with the St. Anthony's Falls Water Power Company. These cables are respectively seven and nine miles long, and have been in use about three years. They transmit three-phase current at 12,000 volts potential. Mr. Burch said that he noticed in the measurements that he had made, that instead of the charging current increasing directly as the voltage, there was a tendency for the lower end of the curve down near the zero to sag below what would be theoretically expected. This conclusion would agree with what I observed. Later I hope to have other instruments at St. Paul to make measurements on the lower part of the curves which results I shall be glad to publish later if we develop anything of interest. Mr. Burch also said that he had made some measurements on his cables by maintain-

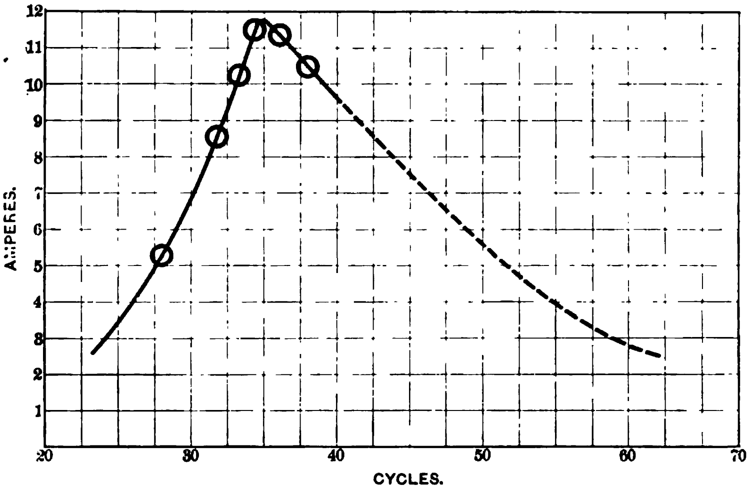


FIG. 17.

ing the voltage constant and varying the number of cycles. All my measurements were made at 60 cycles. Mr. Burch's readings I plotted this afternoon in a rather crude curve, but so that you can all see it. These are the cycles along here [see Fig. 17], and here are the amperes of the charging current on his seven mile cable. As the cycles increase we would naturally expect the charging current would increase in the same proportion; but you will see there is a critical point up here at which the curve seems to bend and come down. Mr. Burch's measurements did not go below this point; but I have drawn the curve showing that the amperes are apparently very materially reduced as we get the cycles up to 60. This is of interest, because it is new, at least to me, and Mr. Burch deserves credit for having demonstrated this phenomenon in his cables. I have talked with the manufacturers of our cables, and they do not seem to have had this point in mind in their measurements for charging current, which were made, one at 25 cycles and the other at 32 cycles. I found that their results did not at all compare with mine as shown on the curves in my paper, and the only explanation I can make of it is that the cycles we are using in St. Paul (60), results in bringing down the charging current very much more than we would expect. Comparing my readings with theirs, I found that my current was in one case at least 50% less than theirs. Mr. Clark, of the Safety company, expected to be here to-night to give us some information in regard to measurements which he himself made. I very much regret that his wife was suddenly taken ill, and he is unable to be present. Mr. Jackson, I hoped would be here, but I see that he is absent. I thank you for your attention.

THE PRESIDENT:—The plant which Mr. Floy described is a very interesting one, and many engineers will be interested in the outcome. There is one point in which this plant is different from most others; instead of transforming down to a reasonably low voltage at the outskirts of the city, and then using overhead wires through the city, the current is carried through underground cables, at the original high voltage to the distributing station. This is a new departure from the usual practice, the success of which will be watched with great interest. I do not believe there are many cases in which high voltages are used in underground cables, but I think Mr. Floy is mistaken in saying that this is the first time. There were some cables shown in the Paris exhibition this year which were subjected to 25,000 and even 30,000 volts continuously, and one of them was a paper cable. The fact that one cable in this installation is made with paper and the other with rubber, is also a very interesting feature of the plan, as it will help engineers to find out whether paper will do as well as the more expensive rubber.

I have no doubt there are others besides myself who would like to know why there is a transformation from three-phase to two-phase, instead of distributing at three-phase; also why some of the current is transformed to continuous current. The paper is open for discussion.

Mr. Townsend Wolcott:—I would like to ask Mr. Floy if any theory was advanced to account for the falling off of the charging current in the cable at high frequency.

Mr. Floy:—As I say, I just received this letter and have not had much time to think over it myself. For the present I have not any explanation to offer.

Mr. Wolcott:—It is a well known fact that the apparent electrostatic capacity of a condenser, or a cable, is different with different frequencies. A paper was read by Dr. Pupin not long ago in which that subject was discussed. I think the observed phenomenon might have some relation to this fact; the so-called absorption of dielectrics. With different materials this would be different. That is, the frequency at which the maximum current was taken, should be different for different insulators.

Mr. Behrend:—I have listened with the greatest interest to Mr. Floy's admirable paper. There is one point about which I wanted to make a few remarks. Mr. Burch's curve is the familiar resonance curve which you always observe if you increase your frequency. If you have an inductance and a capacity in the same circuit, as you have in the case of underground cables, and if then you raise your frequency, you observe this peaky curve. The current increases up to a certain frequency and beyond a certain frequency it decreases. This phenomenon is very old. It is simply the electrical analogy to the mechanical phenomenon presented to us by what is called forced vibration. If you have, for instance, a pendulum vibrating, this pendulum has a certain natural period. If you force this pendulum into vibration then you will observe that up to a certain frequency of the driving force, the excursions of the pendulum increase; they increase up to a point which is called the point of resonance. If you increase your frequency beyond this point, the excursions of the pendulum again decrease. This is an old phenomenon. About thirteen or fourteen years ago that same curve was given by the late Prof. Heinrich Hertz in his researches on electro-magnetic waves. In 1890 it was brought up through the discussions of the resonance phenomena observed on the Ferranti cables between Deptford and London. In connection with that I will say that the Ferranti cable is perhaps the oldest high voltage cable ever laid. It was laid, if I remember rightly, ten or twelve years ago, and carries 11,000 volts, and has carried that voltage for the past ten years. Mr. Kapp then gave before the Physical Society of London a lucid explanation of the resonance effect, and I think you will find his explanation in almost any book on alternating current phenomena.

The Secretary:—I have been particularly interested in this paper for the reason that the last paper that was written by my brother, the late Franklin Leonard Pope, and which was read at the Niagara Falls meeting in 1895, was on the reconstruction of a small plant, where steam power was originally used, and afterwards transmission for about four miles from a water power was substituted. It would be interesting to me, and probably to others, if we could get at the financial reasons which led to this particular change treated by the author to-night; for in the past we have had a great many discussions on the relative cost of water power and steam, and there have been many discussions of the same kind before the American Society of Mechanical Engineers. It has been argued that with a reasonably low price of coal, and using modern steam engines, equal economy could be reached by the use of steam. Some of the mechanical engineers went so far as to say that at Lowell, Massachusetts, for instance, if the water plant had not already been developed and the dam and canal constructed—if the plant was to be put in operation to-day, that they would use steam instead of water power; but having the water power and dam and having invested the money in it, it was cheaper for them to go on, than it was to abandon it. I presume from reading the introduction to this paper that there were good economical reasons for this change, and if it is not the proper time now to give those reasons, I should hope that they might be presented in the future.

The policy of using two kinds of cables, which Mr. Floy brings up, reminds me that several years ago, when I was engaged in the effort of trying to sell underground cables, and one of my customers had begun using something else, that I suggested that he should try more than one kind; for, I told him, it was a question of lapse of time to ascertain whether these cables would endure or not, and if they endured five years and then gave out, and he then tried another kind it might be 25 or 30 years before he found out which was the most serviceable, and I suggested that he lay down some of each kind, including ours, and arrive at the result in the first five years. My argument did not prevail, however, but I am glad to hear that there is somebody else proceeding along that line, and that the author bought all the types of cables he could obtain.

This statement of Mr. Floy's in regard to transmitting power from one city to another enables me to bring up a point that came to my notice abroad last summer that was of considerable interest to me, because I had always supposed that this country had arrived at the acme of protection in various industries. But as we were riding on a line from Geneva to a mountain east of that city, we started on an electric line and changed to a steam dummy which carried us for less than a quarter of a mile to an electric rack railroad up the mountain which was over the boundary line in France. The reason for using this link of steam line was that the French authorities would not permit this electric railroad in France to be operated by a current that was generated by water power in Switzerland.

Mr. Dunn:—As competition in mercantile lines is supposed to be the soul of trade, so competition of opinion seems also to be of use. A few weeks ago I had the pleasure of being at Richmond, Virginia, where there is a dam for the purpose of getting power from the James River to the amount of 14,000 H. P., and there they thought there was no dam like a concrete dam. It had been put across the river in a very substantial manner, and the method of anchoring it was extremely interesting. I presume that some day in years to come we shall know in regard to dams as we shall know in regard to insulation—which is the best kind.

The reference to the use of aluminium is interesting, particularly to me. The subject is one that I think will have more attention as time goes on, and the fact that this line could have been built for nearly $4000 less—if built of aluminium instead of copper shows a premium on the construction of aluminium lines which I am sure will soon result in their general introduction.

Prof. Perrine's paper, read before the Institute at its general meeting in Philadelphia, gave some very interesting particulars about the use of aluminium; in regard, for instance, to the strain it would stand before the sag became too great, and as I remember the paper he also said that owing to the great difficulty of soldering—in fact, there had been no good means yet devised for connecting aluminium lines by soldering—they had twisted the ends of the conductors together without soldering, and experienced no unfavorable results from this method of connecting. There were brought to me to-day some samples of pure aluminium wire which show a new method of making joints, which is a substitute for solder. The process was not revealed, but it consisted in welding the pieces together so thoroughly that you could not tell there had ever been any joint between them. Surely, if aluminium is now to be capable of being welded and connected so thoroughly as this, there is still further reason for its introduction as a conductor.

The value of the figures of nearly $4000, the amount by which it was cheaper to construct an aluminium line over one of copper, would be increased if we could know what the total cost of construction of the line by copper or by aluminium was. In other words, what was the ratio of the cost of the aluminium line to the copper line.

And with regard to the insulation, we are, indeed, in the dark as to how long our insulations are going to last. The whole electrical business is so young that we have not had experience enough to say what will be the behavior of any kind of insulation with the effects of time; whether that insulation be around an underground conductor at high potential, or whether it be lining the slots of a generator. The general opinion seems to be that an insulation, or dielectric strength, follows the same laws as mechanical strength, in possessing an elastic limit and an ultimate limit. While many an insulation will stand a very high voltage for a comparatively long time, it will not withstand that same voltage indefinitely; but if that voltage be within what may be termed its elastic limit, then it will withstand it indefinitely.

I hope that we may have the privilege a few years from now of hearing again from Mr. Floy on the subject of these cables, to see whether 25,000 volts is within or without the elastic limit of his insulation.

THE PRESIDENT:—The process of welding aluminium that Mr. Dunn spoke of was described in this room a month ago, at least I suppose it is the same one. It consists simply in heating the aluminium to a certain definite temperature at which it has been found that it can be welded very readily with a hammer. The temperature is, I believe, that of a dull red heat, at which the metal becomes slightly soft. The process was on exhibition in Paris this year.

THE SECRETARY:—Was it not understood in regard to aluminnium that it could not be welded? There are several processes in the arts that could not be used for aluminium, and it seems to me that welding was one of them. I should suppose that if it could have been welded that this process would have been found out some years ago in working it.

THE PRESIDENT:—I do not know whether this is a new process or not. I only know that it was exhibited in Paris this year as a new process. I thought, as Mr. Pope did, that it was surprising that it had not been known before. The reason probably is that the temperature to which it must be heated must be a very definite one; when it is above or below, the process is probably not successful; at least that is the way I understood it. The welds on the pieces shown in Paris were so perfect that it was impossible to tell where they were.

MR. CALVIN W. RICE:—The attitude of the manufacturers towards the problem of cables for high potentials is very interesting. I have visited the principal factories, and want to say in behalf of manufacturers that there are several who have had full data for a number of years for the manufacture of cables for the potential mentioned in this paper, and have had testing transformers as large as 50 K.W. complete for the testing of their product up to as high as 50,000 volts. I think there are four companies that can test as high as 60,000, and one can test as high as 110,000 volts. A cable that I purchased very recently has been tested—I state this just to show the ability—to 60,000 volts. There is in this city, for work that I am installing, a 400 K.W. transformer for testing the cables at 40,000 volts. I want to suggest something of the commercial conditions which probably obtained during the time of letting this contract. There has been a remarkable amount of cable business. The Philippine cable and the cable to Cuba, Nome and other portions of the world, have demanded all the energies of the cable manufacturers, besides the home consumption, and I have no doubt that at the time this cable was projected there were some features of the specifications respecting delivering, a guarantee which made it impracticable, or perhaps unprofitable, for the other companies which did not enter the competition, to have commercially undertaken this work. There are four or five companies that I can say without hesitation would undertake to build this line.

I am not familiar enough with the paper to ask questions without apology that is due the author for not reading it thoroughly before the lecture. I notice that he stepped up Y and stepped down △, and would like to learn the advantage. Then there are two lines operated in multiple. In the operation of two lines in multiple where one is used as spare in case of trouble on the other line, I would like to ask the author if he puts in safety devices for the capacity of the total plant on each line, or for the capacity of half on each line.

I would like to learn the engineering feature considered in adopting the amount of insulation on this cable, both in the paper and the rubber; also the relative thicknesses between the insulation on the conductors and that in the jacket. I would like also to ask why a jacket construction was decided upon, if it was for any reason other than a commercial one—rather than three conductors having a total insulation on each conductor.

There is one gentleman whose name I would like to see added to the list to whom the author gives credit for engineering, who, from his modesty, we very seldom see in print, Mr. Francis O. Blackwell. He is responsible for a great deal of the successful engineering in long distance transmission of power that we have in America.

DR. SCHUYLER S. WHEELER:—I would like to ask the last speaker a question. I understood him to say that there was in this city at the present time a dynamo of 400 K.W. capacity for testing up to 40,000 volts. I would like to inquire if there is any connection between the capacity of the dynamo and the voltage he wants to test, or if that is only accidental.

MR. RICE:—The charging current for 25 cycles for the cables that are being installed in New York City at 40,000 volts and the longest cable which will extend down to the Battery, will require a transformer of 400 K.W. capacity.

MR. C. E. KNOX:—I would like to ask what is the relative cost of the rubber covered cables and the paper covered cables used underground?

MR. RICE:—The rubber is about double that of the paper for this particular construction of cable such as I am using.

MR. FLOY:—I would answer that inquiry by saying that in this case instead of being double it was about 50% more.

Dr. Wheeler:—I would like to ask once more if I am to understand that the insulation of the cable consumes 400 kilowatts.

Mr. Rice:—It consumes 400 kilowatts apparent energy. I do not know what the power factor is. The volt amperes are 400,000.

Mr. Floy:—Are you testing in place the cables that you are installing now up to 40,000 volts?

Mr. Rice:—We are not quite ready to test. It was simply a question of the delivery by the manufacturer of the transformer which came recently. It has been on order nearly a year, and the switchboard for operating it, etc., is not quite set up.

Dr. Wheeler:—I want to ask once more—I think I understand what is meant by the kilowatts being apparent—in that case would it take an engine or belt drive capable of giving 400 kilowatts?

Mr. Rice:—No, sir; it would not.

Mr. Edward P. Thompson:—I am interested in knowing about the reliability of the potential indicator arrangement that the author has for indicating E.M.F. thirty miles off—whether it is found to allow for drop of electromotive force and so on, and whether it works as satisfactorily as it should for that purpose. What is your personal testimony? I am interested in knowing the fact?

Dr. Sheldon:—I would like to know why you prefer glass insulation to porcelain, if there is any other reason than that of cost?

Mr. Floy:—I will try to answer this long list of questions. We use two-phase current for distribution instead of three-phase, because there were already installed single phase alternating current circuits for supplying current in the outlying districts, and the two-phase seemed to fit into that system a little more satisfactorily than the three-phase would. We use rotary converters, because in the center of the city they already had an Edison three-wire system, and it would have cost considerable to discard that system entirely, and use an alternating current for distribution. They had in use, a number of direct current motors, direct current lamps, etc., which would have been rendered useless.

I am glad to get so much light on this question of decrease in charging current as the cycles are increased. With regard to the use of voltage the opinion seems to prevail that I have made the statement that high voltage had not been used underground. Of course that is not the impression I intended to give, as we all know that high voltages have been used, 10,000 volts or slightly more in London for a number of years, and at Niagara Falls, I believe, they tested up as high as 20,000 volts some time ago, and 12,000 volts have been in constant use between St. Paul and Minneapolis for three years. I had never before known that

30,000 volts was commercially used in Paris this last summer, as I understand the President to state.

The President:—Only as an exhibit.

Mr. Floy:—As to the voltage in the city as most of us know, that is 6600, I believe, and the only *test* that they have made on the cables that I have heard of, and I have talked with the companies that provided the cables, was a maximum of 25,000 volts. Mr. Rice says that when they get his apparatus in order they expect to go higher. Of course I am talking about what *has been* done.

Now, with regard to the cables, it does seem to me only fair that the companies who were enthusiastic about the manufacture of these high-tension cables should get what credit is due them, and a year ago at this time there were no other companies who were ready to undertake the manufacture of those cables on any specifications, whatever their reasons were I don't know, but that they may be ready *now*, because these cables have been put in operation and proved successful. But a year ago at this time there were no other companies I had any communication with, that were willing to consider these cables at all, and I communicated with all the important ones.

With regard to the connections, we planned to use Y connection on both stepping up and stepping down transformers, but we are also planning to use 250-volt rotaries. That would have allowed, with the transformers we planned, two transformers to each rotary. It was found necessary, later, to put in two rotaries of 110 volts each and operate them across the three-wire system in order to give us more flexibility in independently varying the voltage on either side of the Edison three-wire system. In making this change and without increasing the number of step-down transformers, we had to use a delta connection at the sub-station or else run the risk of one transformer burning out and shutting down the whole direct current plant. That was the reason for the change and the use of the delta connected step-down transformers.

With regard to the safety devices, I may say that we do not use any safety devices whatever, the plan being to stall the water-wheels before we let go. There are no fuses or circuit breakers on anything between the water-wheels and the feeders of the switchboards in St. Paul.

Mr. Thompson asked about the indicators. I cannot say anything about them from my own experience. In this plant the indicators have not been put in working condition. Their series transformers have not yet been supplied by the manufacturer, and all I know is the indicators have been used in other places in the West I understand, very satisfactorily.

With regard to the insulators, we used glass because they were cheaper, and because they seemed just as satisfactory, and do not require the minute inspection on installation that porcelain insulators do.

Naturally these figures as to costs of the plant are most interesting. We would all like to know what they are. At the same time I do not feel quite at liberty to disclose very much along that line. Of course it is easy enough for any one to sit down and figure the cost of our copper and come pretty close to it; so I do not have any hesitation in saying that the copper cost about $30,000 for the 24 miles. We would have saved between $3,000 and $4,000 in substituting aluminium for copper.

MR. F. C. BATES:—I should like to change a possible impression that may have been created by Mr. Floy's statement, that no other cable manufacturers other than those mentioned in this paper, could be induced to bid on his specifications for this installation.

In Mr. Floy's efforts on behalf of his clients, his specifications were drawn in such a way as to put the greater part of the financial risk on to the manufacturer. As it was an installation involving some risk, and as at that time there was a great deal of attractive business offered, *at least one manufacturer* declined to bid purely on commercial grounds, and not from an engineering standpoint.

MR. EDWARD P. THOMPSON:—Mr. Floy said that more credit should be given to the two companies who laid conductors underground to carry 25,000 or more volts. Of course it is to their credit to be so enterprising as to do it, and it may be to their discredit if it does not work well. But the point is that the names of the companies do not seem to be given in the paper, although names are given very freely, and I think it is perfectly proper—trademark names and names of instruments, and so on. But I do not find the names of those two companies, and in making these remarks I would say that I have no connection with them, and I do not know who they are, but I do not see any reason why their names should not be mentioned, because we cannot give them credit unless we know who they are.

THE SECRETARY:—The position taken by Mr. Bates is exactly the same that I took in talking with one of the gentlemen who examined this paper as to what I would have done had I been a manufacturer of cables. It appeared to me that if there was any other way of keeping the plant busy, I should not undertake to make cables for an experiment of that kind, and put so much capital into them and guarantee them for five years out West, and under unusual conditions, or conditions with which I was not familiar.

In regard to Mr. Thompson's inquiry in reference to the make of cables, I think if he is familiar with the cable market he will readily know who the makers of the National and Safety cables are.

MR. MAILLOUX:—With reference to the interesting remarks made about the relative cost of aluminium and copper wire, I may state that I have had occasion to figure it recently in connection with some transmission lines which were in prospect, and I found that with copper at 21½ or 22 cents, the cost of line material for the same conductivity, using aluminium, bore to copper the relation of about 17 to 22. With copper wire at 21½ or 22 cents a pound, the same conductivity and carrying capacity with aluminium wire would cost the same as if copper were reduced to about 17 cents. Hence if copper falls down to 17 cents, and the price of aluminium remains stationary, the same conductivity with the two metals, costs about the same. The cost of the line, of course, includes a constant plus, a variable quantity, the constant being the cost of the pole line, which, for a given case, is pretty nearly independent of all conditions, including the size of line, because ordinary precaution dictates the use of certain size poles and a certain spacing, etc., which are very little changed, no matter what may be the number of lines put upon the poles. The number and size of cross-arms may be changed, but these do not affect the cost very much. The number and cost of insulators, for a given case, may be considered constant. On the other hand, the cost of the metal portion of the line will increase with the conductivity. It will also increase with the number of lines, if two or more complete lines are to be put upon the same poles; the increase being largely due to the increase in number of insulators.

With regard to underground cables, I have been surprised to find that there is much difference in the method of constructing them here and in Europe. Some three years ago I had occasion to investigate the matter carefully in Eastern Europe for some clients who were interested in having the subject studied for them. I was surprised to find that in Austria, in Hungary, and even in the eastern portion of Germany, cables are being made for use with pressures varying from 2,000 to 12,000 volts, which, outwardly at least, are very little different from what we call "triple braid weather-proof wire" in this country. I visited two large factories where cables for high pressures were being made by wrapping the copper conductor with three simple braids of cotton or jute, or sometimes with linen or cotton thread, the braids being somewhat thick. For a 10,000 volt cable the total thickness would be perhaps from one-eighth to three-sixteenths of an inch. Each conductor receives its own wrapping; and two, three, or more of these conductors (as many as are required for the purpose), are bunched together, and the cable sheath of lead is put over them, after they have been treated with an insulating compound. The cables are insulated simply by baking the moisture out of them and by passing them through a compound, the exact composition of which is a secret. I have seen these cables tested up to 25,000 volts, the entire cables being put into a vat of water just as they came from the factory, with the two free ends sticking out of the vat, and all the conductors being coupled together in parallel, and the source of potential being connected between the cables and the water in the vat, so as to give every possible chance for leakage. I have seen cables with one or two wrappings of this braid, of two or three millimeters total thickness, treated with a compound and covered with a sheathing of lead, subjected to pressures of 15,000 volts for an indefinite length of time without apparent effect. The central station manager in one of the large cities in Hungary told me that underground work would scarcely be possible there unless they could obtain underground cables at much lower cost than that at which they could be obtained, if rubber or any expensive insulation had to be used. It is a matter of some surprise to me, therefore, to find that, in this country, we have to resort to such expensive processes of cable manufacture in order to obtain cables that can withstand the pressure of 6,000 to 10,000 volts.

MR. RICE:—I would like to speak upon the point of the necessity of a large insulating wall for high pressures. We have cables in New York City which have been in service about eleven years, and we have had considerable experience, and we have found from actual experience the necessity of it, and for the 6600-volt work we consider it essential that there be at least 10/32 of rubber insulating wall, of a compound as good as that mentioned in the paper to-night, *i. e.*, about 35 per cent. of rubber compound, in order to insure an absolutely safe cable.

In connection with Mr. Mailloux's remarks regarding the testing of cables with jute or cotton insulation at such high voltages, I should like to ask the capacity of the transformers that were used in testing, and if you observed how the potential was measured at the time of the test.

MR. MAILLOUX:—As near as I can recollect, in one of the factories that I visited, the machine used was of about 25-kilowatts capacity. It generated a low electromotive force which was raised by step-up transformers of sufficient capacity (apparently suitable for the machine), and the potential was measured by an electrostatic voltmeter of the Kelvin type; so that there could be no doubt as to the pressure. The voltmeter was connected directly at the terminals of the transformer. I have seen this alternating pressure remain in application for fifteen or twenty minutes. In fact, I was allowed to let it continue as long as I wished it to stay. I did not care to have it tried any longer than ten minutes. I was perfectly satisfied after even five minutes.

[Adjourned.]

A paper presented at the 150th Meeting of the American Institute of Electrical Engineers, New York, January 25th, 1901, President Hering in the Chair.

AIR-GAP AND CORE DISTRIBUTION.

THE MAGNETIC FLUX AND ITS EFFECT UPON THE REGULATION AND EFFICIENCY OF DYNAMO-ELECTRIC MACHINERY. PART III.

BY W. ELWELL GOLDSBOROUGH.

At the Omaha meeting of the INSTITUTE I presented for your consideration an outline of a method[1] for the determination of the surface density of the magnetic flux at the air line boundaries of masses of magnetic material, when such masses are subjected to the influence of known electro-magnetic forces.

In the present paper it is my purpose to elaborate the method referred to, and to present the results of further experimental researches in support of the accuracy of the theoretical treatment.

By way of an introduction to new matter it is well to review the concept of the interaction of the elements involved, which is the basis upon which all amplifications of the method rest. This concept is simply but effectively developed by a consideration of such an arrangement of parts as is shown in Fig. 1. Here the armature is taken as a plane extending indefinitely to right and left. The pole-piece is a rectangular block extending indefinitely in a vertical direction above the armature, and having perfectly square corners. The length of the air-gap or the vertical distance from the pole-face to the armature surface is the same at all points. Both the armature and the pole-piece extend indefinitely at right angles to the plane of the paper, Fig. 1 being only a cross-sectional view of the apparatus assumed.

---

[1] TRANSACTIONS, vol. XV., pp. 515–529, 1898.

Suppose, now, that an M. M. F. is applied to the pole-piece to set up a magnetic field in the air-gap. Since the permeance of the pole-piece and of the armature is high, we can consider, for all practical purposes, that all points on the sides and face of the pole-piece are at the same potential relatively to the armature surface, and that all points on the armature surface are at the same potential relatively to the pole-piece, and that, therefore, a constant difference of magnetic potential exists between points on the pole-piece and points on the armature. That is, for all practical purposes, there is the same difference of potential between (*a–o*) as there is between (*c–n*) or (*d–m*).

And, *the number of lines of force that pass between any pair of points on the pole-piece and the armature respectively* (as *n–d*, in the plane of the paper) *is inversely proportional to the distance*[1] *between them. And the strength of the magnetic field at the surface of the armature at any point* (as *d*) *is proportional to the sum of the reciprocals of the distances of the point* (*d*) *from all the points on the perimeter of the pole-piece made by a section-plane passing through the point* (*d*), as in Fig. 1.

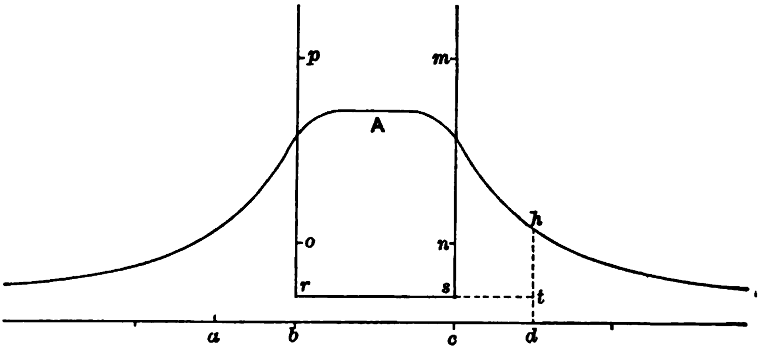


Fig. 1.

That this statement of the law of the variation of the strength of the magnetic field holds true under the limitations imposed, is readily apparent when it is remembered that the lines of magnetic force that radiate from any point on the line cut in the polar surface by the section-plane, may be considered as confined within the limits of the section-plane, and to create a

---

[1] In measuring these distances it must be remembered that the most direct path *in air* must be taken, as (*d–r–o*) Fig. 1, *not* (*d–o*) direct.

field varying in its intensity inversely as the distances taken from the point. An infinite number of such section-planes, arranged parallel to one another and at right angles to the polar and armature surfaces, and, therefore, extending in a pile to infinite distances above and below the plane of the paper, will hold within their surfaces the magnetic lines emanating from the pole, for the magnetic forces at similarly situated points maintain such an equipoise by mutual repulsion as to prevent themselves from escaping the confines of their respective planes. For such cases the law of *inverse squares* does not hold, whereas, the law of *inverse proportion* does hold.

If the source of M. M. F. be brought within the more immediate vicinity of the armature surface, the conditions of potential distribution are at once modified. Suppose the energizing coil

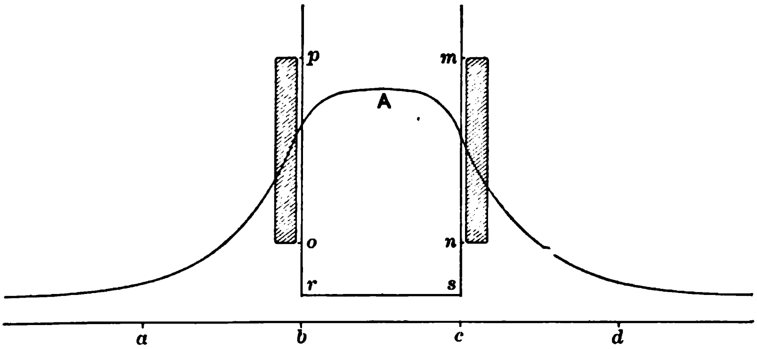


FIG. 2.

to occupy a position between (*o–n*) and (*p–m*). Then, as before, there will be a constant difference of potential between (*a–o*) and (*c–n*), but the potential difference between (*d–m*) will be zero. Under these conditions, then, the difference of potential between points on the polar surfaces below (*o–n*) and the armature is a maximum. The difference of potential between polar points above (*p–m*) and the armature surface is zero, and the potential between the armature and points on the polar surfaces (*n–m*) and (*o–p*) will be proportional to the distance the points are within the coil and above (*o–n*), divided by the height of the coil (*n–m*).

Therefore, *where potential variations occur, the number of lines of force that pass between any pair of points on the pole-*

piece and the armature respectively, is directly proportional to the potential between the points, and inversely proportional to the distance between them. And the strength of the magnetic field at the surface of the armature at any point is proportional to the sum of the products of the differences of potential between the point and all the points on the perimeter of the pole-piece, by the respective reciprocals of the distances of the point from all the points on the perimeter of the pole-piece (as shown in Fig. 2).

ARMATURE SURFACE DENSITY.

The curve A in Fig. 1 represents the distribution of the magnetic flux at the *surface of the armature* as determined by the foregoing method; for the length of any ordinate (*h*–*d*) at any point (*h*) on this curve is equal to the sum of the reciprocals of the distances of the foot of the ordinate (*d*) from all points on the pole-piece. The curve A extends indefinitely to right and left, and is asymptotic to the surface of the armature. The curve indicates that the strength of the magnetic field does not diminish as rapidly as is usually supposed after the limits of the working air-gap proper are passed.

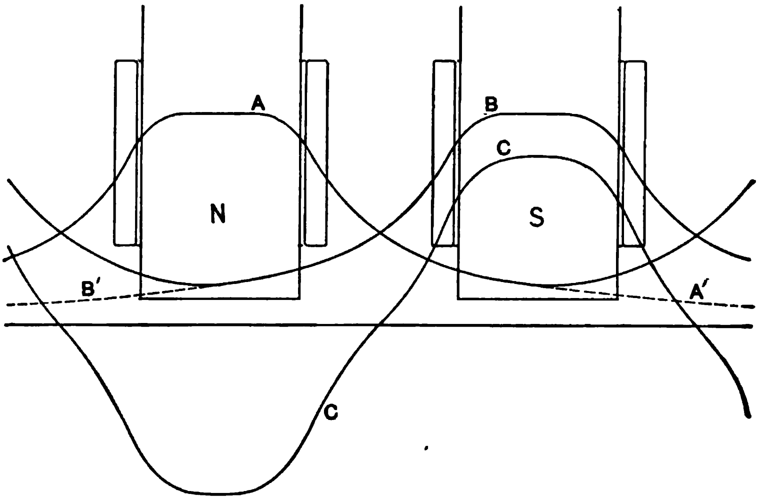


FIG. 3.

Fig. 2 illustrates the field strength at the surface of the armature when a pole is acting upon it which carries an energizing coil placed but slightly above the pole corners. The ordinates of this curve are not so high as those of curve A, Fig. 1, on account of the difference in the potential distribution in the two cases. Suppose we bring up another pole, similar in every respect to the first, except that it is of opposite polarity. It will tend to set up a field density at the surface of the armature that is represented by curve B of Fig. 3; but since this magnetic field is opposed to that of the pole N, a field will result that is equal to the difference of the superimposed fields, or to the field strength represented by the curve C, Fig. 3. As a result of the subtraction, the flux density is shown to be zero at any point on the surface of the armature that is midway between the two poles, and that the sign of the field is reversed at such point. In this case the strength of the field *at the surface of the armature* is greatest at the center of the poles and diminishes to right and left. The reduction in the strength of the field under the pole corners is marked, and the form of the fringing field is clearly outlined. It is to be further remarked that the contour of the curve C of flux distribution changes its form as the distance between the poles N and S is varied.

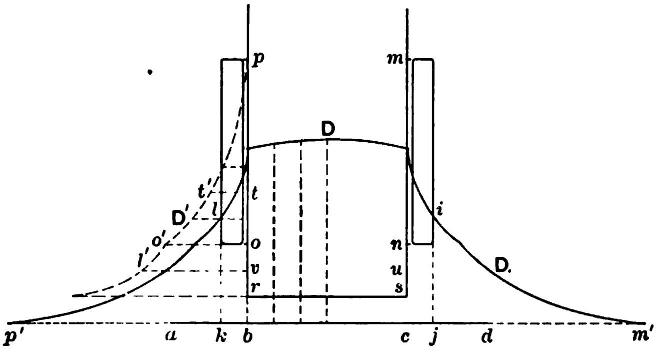


FIG. 4.

POLE FACE SURFACE DENSITY.

The flux entering the surface of the armature from any one of a number of poles acting upon the armature has been shown to be proportional to the ordinates of the curve C, Fig. 3. Now this flux must of necessity largely emanate from the pole face that is immediately above the surface affected, and by applying the process of reciprocal summation from points on the polar perimeter, to all points on that part of the armature surface which is covered by the curve C, between two consecutive zero points, it is possible to develop the curve of pole face surface density. The results of such a summation are shown in Fig. 4.

The ordinates of the curve D represent intensities of the flux leaving successive points on the perimeter (*p–r–s–m*), due to the presence beneath the pole of a part (*a–d*) of the armature surface that is equal to the polar pitch. The curve D is plotted against the polar perimeter (*p–r–s-m*) developed into the straight line (*p′–b–o–m′*). The ordinate (*j–i*) represents the intensity of the flux leaving the pole tip at (*u*), the ordinate above (*o*) represents the intensity of the flux leaving the pole corner (*r*), and so on for other points. All of the flux that leaves the pole below the line (*o–n*) is acted on by the maximum M. M. F. between the pole and the armature. The flux leaving points on the pole above (*o–n*) is acted on by M. M. F's which diminish gradually until (*p–m*) is reached, at and above which there is no M. M. F. acting to produce a field, and therefore no flux leaving the surfaces.

This diminution in the potential is the cause of the slight peak in the curve D on either side of the pole. The ordinates of these peaks represent flux intensities at (*o*) and (*n*) respectively, as is indicated clearly at (*o′*) of the curve D′. Curve D′ is the same as the pole tip portion of curve D, only it is plotted directly against the pole tip or side polar surface. If one loop of the curve C, Fig. 3, is integrated, and this area then subtracted from the central portion of the area included between curve D and the base line (*p′–m′*), the area D–*i–j–k–l*–D will be taken. This area is then proportional to the flux leaving the pole and entering the armature, and as from any one elementary part of an area the flux can only flow in one direction, the polar limits of the area D–*i–j–k–l*–D should be pole tip points (*u* and *v*) above which none of the flux leaving the pole enters the armature.

POLAR SURFACE LEAKAGE FLUX.

In the case of two electrically energized poles, such as poles N and S of Fig. 5, there is always a considerable flow of magnetic flux between them. If we consider the armature entirely removed the whole force of the M. M. F. acting will be expended in setting up a leakage field between the poles. In-as-much as the M. M. F. acting and producing this field is the resultant of two coils, instead of being due to one only, the difference of potential between adjacent pole faces will be twice that acting between any pole face and the armature. Furthermore, the difference of potential between the pole faces (*s*) and the yoke

(m') will be equal to the M. M. F. acting between the pole face and the armature, or to one-half the M. M. F. acting between adjacent pole faces. Therefore, by the application[1] of the method

---

[1] NOTE.—By carrying out the application of the principles upon which the method depends to the limit, in the calculation of leakage, it will be found that any inconsistency which there may seem to be in the statement, "there will be an appreciable amount of leakage flux passing from the upper . . . polar surfaces," vanishes. To accomplish this, no surface between which and the point from which the summation is taken there is the least potential difference should be neglected. To be more explicit, let us refer to Fig. A, and consider the flux entering the upper pole face at the point (a). There is evidently a positive difference of potential between (a) and every point on the perimeter (b–c–d–e–f–g–h–i–h'–g'–f'–e'–d'–c'–b') of the section of the cylindrical system shown in the figure, as the energizing coils occupy the spaces between (b–b'), (d–d') and (h–h'), (f–f'). Therefore the flux entering at (a) is proportional to the summation of reciprocals, taken with proper reference to M. M. F., from all parts of the perimeter. If we consider any other point, as for example (c), it is found that there is a positive potential between (c) and all points on the perimeter (c–d–e–f–g–h–i–h'–g'–f'–e'–d'–c') but a negative potential between (c) and all points on the perimeter (c–b–a–b'–c'). Therefore, the flux entering at any point below (b–b') as (c), is proportional to the summation of reciprocals, *taken with proper reference to* M. M. F. *and sign*. The result of a complete set of summa-

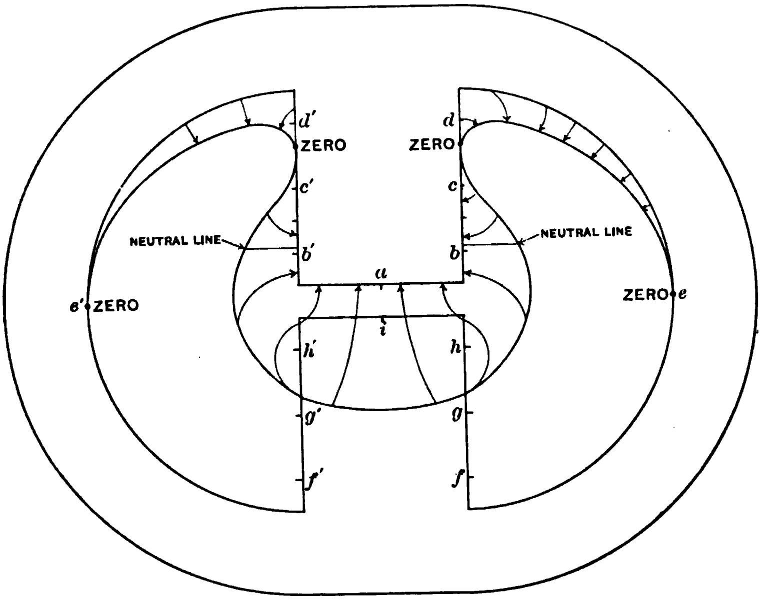


FIG. A.

as outlined there will be an appreciable amount of leakage flux passing from the upper, as well as the lower polar surfaces, inclosed by the energizing coils.

The curve E of Fig. 5 shows approximately (see foot-note) the extent of the leakage field developed between the pole N and the pole S. The flux indicated by the curve E′ passes to the pole at the left of pole N. The complete amount of leakage flux from the pole N is represented, of course, by the combined areas included between the curves E and E′ and the polar perimeter.

In taking the summations for these leakage curves, the whole surface of pole S, $(m'-s'-r'-p')$ must be included, the different portions, $(m'-n')$, $(n'-s')$, $(s'-r')$, $(r'-o')$ and $(o'-p')$ being treated with proper reference to the M. M. F. acting between each, and the point on the pole N from which the summation is taken.

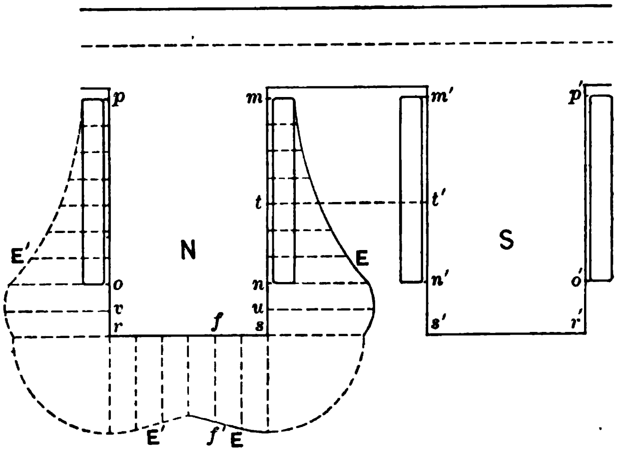


FIG. 5.

---

tions taken with reference to M. M. F. and *sign* for a series of points is the development of such a flux distribution curve as is diagrammatically indicated about the upper pole and ring of the figure, which shows the development of zero flux points between (d–c) and (d′–c′) above and below which there is an exchange of flux between the poles sides and the ring, and the further development of two neutral points between (c–b) and (c′–b′), below which there is an interchange of flux directly between the poles. For practical purposes it does not seem necessary to extend the process of taking the summation beyond the limits of the pole of opposite sign, as the area of the leakage field curve so obtained practically equals the sum of the areas developed by the more elaborate application.

THE COEFFICIENT OF MAGNETIC LEAKAGE.

To determine the actual distribution of the flux over the polar surfaces, the leakage field of Fig. 5 must be superposed upon the pole face distribution curve of Fig. 4. This super-position is shown in Fig. 6. The points (*i*) and (*l*), at which the curves D and E cross, determine the limits of the useful and leakage fields of the system. The flux shown by those parts of the curve E which lie above (*l–v*) and (*u–i*) set the boundaries of the leakage field, while the parts of the curve D which lie below (*s–v*) and (*u–i*) mark the extent of the useful field. It is, therefore, evident that the coefficient of magnetic leakage of the system will be equal to the ratio of the sum of the useful and leakage areas (*u–m–g–i–s–r–l–f–p–v–u*) to the useful area (*u–i–s–r–l–v–u*). By this combination of curves we have determined the final factor in the exploration of an electro-magnetic system that is composed of one or more poles acting upon a plane surfaced armature.

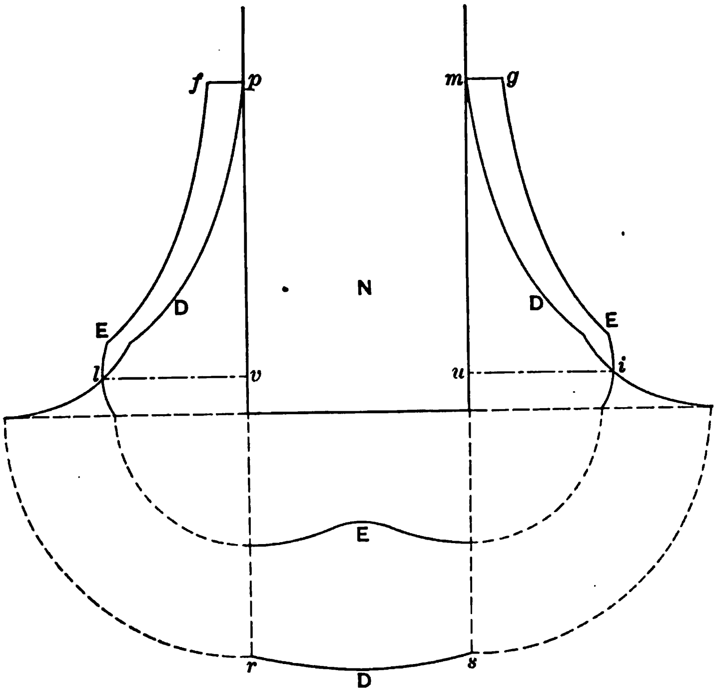


FIG. 6.

THE EFFECT OF SLOTS.

When slots or grooves are cut in the surface of the armature they diminish the total flux passing from the poles to the armature surface by a considerable amount. In making a calculation of the distribution of the flux over the bottom and sides of a slot the same method of reciprocal summation should be followed that is used to determine armature surface density curves, such as curve A of Fig. 2. However, owing to the fact that the sides of the slot materially diminish the extent of the approach usually open to flux as it passes from the pole to the armature, it is wrong to consider the full value of the ordinate obtained by this summation as representing the flux intensities around the slot surfaces.

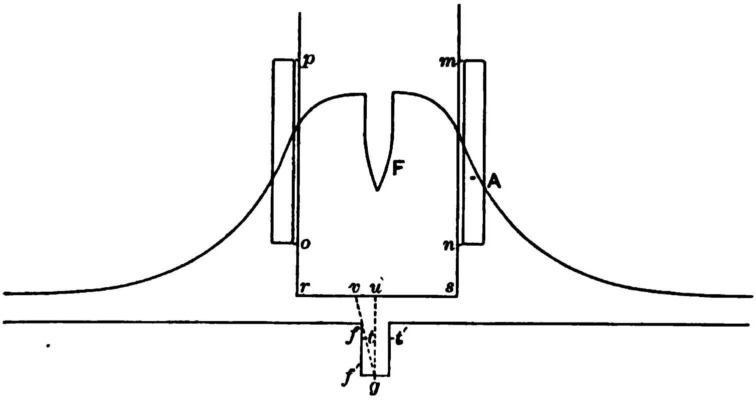


FIG. 7.

If the summation is taken in the usual manner for such a point as (*g*), at the bottom of the slot shown in Fig. 7, the result, by comparison with a similar summation for the point (*f*) at the edge of the slot, will only be decreased by an amount that is inversely proportional to the average increase of the distance of the point (*g*) from the pole surface points. If the confining influence of the sides of the slot was removed, this decrease would represent a true condition; but as the confining influence cannot be removed, it greatly reduces the permeance of the path open to the flux, and a contraction co-efficient has to be introduced to reduce the flux ordinate in proportion to the average decrease in the width of the approach imposed by the dimensions of the slot. By this means a correct estimate of the effect of the slots upon the permeance of the air-gap is made possible.

MATHEMATICAL TREATMENT.

The calculation of such flux distribution curves as have been shown in the preceding figures is best accomplished by an application of the calculus.

In developing a series of formulas to cover all the probable cases let us first turn to Fig. 1. In determining the value of the ordinate at (d) three operations are necessary. One integration will give the summation of reciprocals from (d) over the surface (r–p), but a second must be taken for the surface (s–r) and a third for the surface (s–m).

Consider first the surface (r–p), which is at a constant difference of potential relatively to (d). Let (y) denote the reciprocal of the distance of any point on the surface (r–p) from (d), and x the distance of any point on the surface (r–p) from (d) measured around the pole corner (r), then, if the distance (d–r–p) $= x_m$, the maximum value attained by x, and (d–r) $= x_n$, the minimum value attained by x, since

$$y = \frac{1}{x}$$

therefore

$$\sum_{x_n}^{x_m} y_{r-p} = \int_{x_n}^{x_m} \frac{dx}{x} = \log_e(x) \Big[_{x_n}^{x_m} = \log\left(\frac{x_m}{x_n}\right) \qquad (1)$$

For the summation over the second surface let (y) denote the reciprocal of the distance of any point on the surface (s–r) from (d), (x) the distance of any point on (r–s) from (t), and (a) the constant length (d–t), then

$$y = \frac{1}{\sqrt{a^2 + x^2}}$$

and if $x_m = (t–r)$ and $x_n = (t–s)$

$$\sum_{x_n}^{x_m} y_{s-r} = \int_{x_n}^{x_m} \frac{dx}{\sqrt{a^2 + x^2}} = \log_e\left(x + \sqrt{a^2 + x^2}\right) \Big[_{x_n}^{x_m}$$

$$= \log_e\left(\frac{x_m + \sqrt{a^2 + x^2_m}}{x_n + \sqrt{a^2 + x^2_n}}\right) \qquad (2)$$

Since the summation over the surface (s–m) is accomplished by the application of formula (2), in which the value of (a) is the distance (d–o), therefore, making $x_\mathrm{m} = (o\text{–}m)$ and $x_\mathrm{n} = (o\text{–}s)$,

$$\sum_{x_\mathrm{n}}^{x_\mathrm{m}} y_{\mathrm{s-m}} = \log_\mathrm{e}\left(\frac{x_\mathrm{m} + \sqrt{a^2 + x^2_\mathrm{m}}}{x_\mathrm{n} + \sqrt{a^2 + x^2_\mathrm{n}}}\right) \tag{2}$$

and the value of the ordinate at the point (d), or

$$(d - h) = \sum_{x_\mathrm{n}}^{x_\mathrm{m}} y_{\mathrm{r-p}} + \sum_{x_\mathrm{n}}^{x_\mathrm{m}} y_{\mathrm{s-r}} + \sum_{x_\mathrm{n}}^{x_\mathrm{m}} y_{\mathrm{s-m}}$$

The ordinates of the other points on curve A, Fig. 1, are obtained, by the application of (1) and (2), in a similar way.

Where the energizing coil surrounds the pole as in Fig. 2, a modification has to be introduced in taking summations of reciprocals over the surfaces (o–p) and (n–m), owing to the variations in the M. M. F. within the coil. However, the surfaces (r–o) and (s–n) of Fig. 2, are treated in the same way as the surfaces (r–p) and (s–m) are treated in the case of Fig. 1.

In considering the summation from (d) to (o–p), provision must be made for the fact that the M. M. F. between (o) and (d) is a maximum while the M. M. F. between (p) and (d) is zero. To do this, a *proportional* M. M. F. *factor* must be introduced into the differential of (1), which has the value one when $x = (d\text{–}r\text{–}o) = x_\mathrm{n}$, and the value of zero when $x = (d\text{–}r\text{–}p) = x_\mathrm{m}$.

$$\frac{A - x}{B},\ \text{in which } A = x_\mathrm{m} \text{ and } B = x_\mathrm{m} - x_\mathrm{n},\ \text{or } \frac{x_\mathrm{m} - x}{x_\mathrm{m} - x_\mathrm{n}}, \tag{11}$$

is such a factor, and therefore, in Fig. 2,

$$\sum_{x_\mathrm{n}}^{x_\mathrm{m}} y_{\mathrm{o-p}} = \int_{x_\mathrm{n}}^{x_\mathrm{m}} \frac{A - x}{B} \frac{dx}{x} = \frac{A}{B} \log_\mathrm{e}(x) - \frac{x}{B} \Big[_{x_\mathrm{n}}^{x_\mathrm{m}}$$

$$= \frac{x_\mathrm{m}}{x_\mathrm{m} - x_\mathrm{n}} \log_\mathrm{e}(x) - \frac{x}{x_\mathrm{m} - x_\mathrm{n}} \Big[_{x_\mathrm{n}}^{x_\mathrm{m}}$$

$$= \frac{x_m}{x_m - x_n} \log_e \left(\frac{x_m}{x_n}\right) - 1 \qquad (3)$$

In the case of the surface (*n–m*), Fig. 2, the same M. M. F. reduction factor is introduced into the differential of (2) as in the case just treated. Then,

$$\sum_{x_n}^{x_m} y_{n-m} = \int_{x_n}^{x_m} \frac{A-x}{B} \frac{dx}{\sqrt{a^2+x^2}} = \frac{A}{B} \log_e (x + \sqrt{a^2+x^2}) -$$

$$\frac{\sqrt{a^2+x^2}}{B} \Big[_{x_n}^{x_m}$$

$$= \frac{x_m}{x_m - x_n} \log_e (x + \sqrt{a^2+x^2}) - \frac{\sqrt{a^2+x^2}}{x_m - x_n} \Big[_{x_n}^{x_m}$$

$$= \frac{x_m}{x_m - x_n} \log_e \left(\frac{x_m + \sqrt{a^2+x_m^2}}{x_n + \sqrt{a^2+x_n^2}}\right) - \frac{\sqrt{a^2+x_m^2} - \sqrt{a^2+x_n^2}}{x_m - x_n} \qquad (4)$$

In determining the value of the ordinates of the pole face flux distribution curve the formulas so far developed only suffice in part. The length of such an ordinate as (*o–o′*) of Fig. 4, is determined by two operations, one giving the summation over the surface (*a–b*) and the other the summation over (*b–d*). In the former case formula (2) is used, (*a*) being made equal to the distance (*o–b*) and x varying in value from zero at (*b*) to (*b–a*) at (*a*).

To effect the second summation a new expression is necessary, as the distance (*o–r*) enters as an independent constant in determining each reciprocal. Let x equal the distance from (*b*) of any point on (*b–d*), (*a*) equal the constant distance (*r–b*) and (*b*) the constant distance (*o–r*), then, putting $x_m = (b–d)$, and $x_n =$ zero,

$$y = \frac{1}{b + \sqrt{a^2+x^2}}$$

and

$$\sum_{x_\mathrm{n}}^{x_\mathrm{m}} y_{\mathrm{b-d}} = \int_{x_\mathrm{n}}^{x_\mathrm{m}} \frac{dx}{b + \sqrt{a^2 + x^2}}$$

therefore, when $a > b$:–

$$\sum_{x_\mathrm{n}}^{x_\mathrm{m}} y_{\mathrm{b-d}} = \log_e (x + \sqrt{a^2 + x^2}) - \frac{2\,b}{\sqrt{a^2 - b^2}} \tan^{-1}\left(\frac{x + b + \sqrt{a^2 + x^2}}{\sqrt{a^2 - b^2}}\right) \Bigg[_{x_\mathrm{n}}^{x_\mathrm{m}}$$

$$= \log_e \left(\frac{x_\mathrm{m} + \sqrt{a^2 + x^2_\mathrm{m}}}{x_\mathrm{n} + \sqrt{a^2 + x^2_\mathrm{n}}}\right) - \frac{2\,b}{\sqrt{a^2 - b^2}} \Bigg[\tan^{-1}\left(\frac{x_\mathrm{m} + b + \sqrt{a^2 + x^2_\mathrm{m}}}{\sqrt{a^2 - b^2}}\right)$$

$$- \tan^{-1}\left(\frac{x_\mathrm{n} + b + \sqrt{a^2 + x^2_\mathrm{n}}}{\sqrt{a^2 - b^2}}\right)\Bigg] \qquad (5)$$

when $a = b$:–

$$\sum_{x_\mathrm{n}}^{x_\mathrm{m}} y_{\mathrm{b-d}} = \log_e (x + \sqrt{a^2 + x^2}) + \frac{2\,a}{x + a + \sqrt{a^2 + x^2}} \Bigg[_{x_\mathrm{n}}^{x_\mathrm{m}}$$

$$= \log_e \left(\frac{x_\mathrm{m} + \sqrt{a^2 + x^2_\mathrm{m}}}{x_\mathrm{n} + \sqrt{a^2 + x^2_\mathrm{n}}}\right) + \frac{2\,a}{x_\mathrm{m} + a + \sqrt{a^2 + x^2_\mathrm{m}}}$$

$$- \frac{2\,a}{x_\mathrm{n} + a + \sqrt{a^2 + x^2_\mathrm{n}}} \qquad (6)$$

and when $a < b$:–

$$\sum_{x_\mathrm{n}}^{x_\mathrm{m}} y_{\mathrm{b-d}} = \log_e (x + \sqrt{a^2 + x^2})$$

$$- \frac{b}{\sqrt{b^2 - a^2}} \log_e \left(\frac{x + \sqrt{a^2 + x^2} + b - \sqrt{b^2 - a^2}}{x + \sqrt{a^2 + x^2} + b + \sqrt{b^2 - a^2}}\right) \Bigg[_{x_\mathrm{n}}^{x_\mathrm{m}}$$

$$= \log_e \left(\frac{x_\mathrm{m} + \sqrt{a^2 + x^2_\mathrm{m}}}{x_\mathrm{n} + \sqrt{a^2 + x^2_\mathrm{n}}}\right)$$

$$- \frac{b}{\sqrt{b^2 - a^2}} \log_e \left[\left(\frac{x_m + \sqrt{a^2 + x^2_m} + b - \sqrt{b^2 - a^2}}{x_m + \sqrt{a^2 + x^2_m} + b + \sqrt{b^2 - a^2}} \right) \right.$$

$$\left. \left(\frac{x_n + \sqrt{a^2 + x^2_n} + b + \sqrt{b^2 - a^2}}{x_n + \sqrt{a^2 + x^2_n} + b - \sqrt{b^2 - a^2}} \right) \right] \qquad (7)$$

And, therefore, since in the present case of point (*o*), (*a*) is less than (*b*), formula (7) gives the desired summation over (*b*–*d*).

For the summation over this surface (*b*–*d*) from (*v*), formula (6) is used, as $(v–r) = b = (r–b) = a$. For points between (*v*) and (*r*) formula (5) would be used, as (*a*) is greater than (*b*) for such points.

When estimating the intensity of the flux leaving points on the side of the pole above (*o*–*n*), the value of the proportional ordinate is first obtained in the usual way, and then reduced in direct proportion to the distance the explored point is from the top of the coil. The value of the ordinate to curve D′ at (*t*), Fig. 4, is equal to,—

$$(t - t') = \left[\sum_{x_n}^{x_m} y_{b-a} \text{ by } (2) + \sum_{x_n}^{x_m} y_{b-d} \text{ by } (7) \right] \frac{(t-p)}{(o-p)} \qquad (14)$$

where $x_m = (b–a)$ in (2), and (*b*–*d*) in (7), and $x_n = o$ in both (2) and (7). In a case such as is shown in Fig. 4, formulas (2), (5), (6) and (7) are all that are needed.

In the determination of data for plotting leakage flux curves, like those shown in Fig. 5, other forms are encountered. The value of the flux ordinate at (*s*) is determined by the application of (2) to (*s*′–*n*′) and (1) to (*s*′–*r*′–*o*′), each result being doubled, as there is double the pressure between the poles that there is between a pole and the armature. For the summations over (*n*′–*m*′) and (*o*′–*p*′), however, special proportional M. M. F. factors must be used as the proportional value of the M. M. F. between (*s*) and (*n*′–*o*′) is 2, and between (*s*) and (*m*′–*p*′) is one.

To find the value of the proportional M. M. F. factor, put $x_n = (s'–n')$ and $x_m = (s'–m')$ in,—

$$\frac{A - x_n}{B} = 2 \text{ and } \frac{A - x_m}{B} = 1$$

then

$$B = \frac{A - x_n}{2}, \text{ and also, } B = A - x_m$$

therefore $$A - x_n = 2\,A - 2\,x_m$$

or $$A = 2\,x_m - x_n$$

and $$B = x_m - x_n$$

and the value of the proportional M. M. F. factor is

$$\frac{A - x}{B} = \frac{2\,x_m - x_n - x}{x_m - x_n} \tag{12}$$

Now writing $A = (2\,x_m - x_n)$, and $B = (x_m - x_n)$ in (4) and (3), (4) and (3) can be applied directly to the obtaining of complete summations over the surfaces $(n'\text{–}m')$ and $(o'\text{–}p'$, respectively. The $[y_{(n'-m')}]$ and $[y_{(o'-p')}]$ values so determined must not be doubled before being added to the results obtained above for the surfaces $(s'\text{–}n')$ and $(s'\text{–}r'\text{–}o')$, as such correction is taken care of by the proportional M. M. F. multiplier of (12).

In obtaining summations for points such as (t), located on the pole surface within the coil, special care must be taken to provide correct proportional M. M. F. factors. For the surfaces $(n'\text{–}s')$ and $(s'\text{–}r'\text{–}o')$, to which (2) and (1) apply respectively, constant value proportional M. M. F. factors

$$\text{equal to } \frac{(t - m) + (m' - n')}{(m - n) + (m' - n')} \text{ must be used.} \tag{13}$$

For the surface $(o'\text{–}p')$ the variable proportional M. M. F. factor must range in value from

$$\frac{(t - m) + (m' - n')}{(m - n) + (m' - n')}, \text{ when } x = (t - s' - r' - o') = x_n, \text{ to}$$

$$\frac{(t - m)}{(m - n) + (m' - n')}, \text{ when } x = (t - s' - r' - p') = x_m \text{ and}$$

be applied in (3).

Similarly the proportional M. M. F. factor for the surface

$$(t' - m') \text{ must vary between } \frac{(t - m) + (t' - m')}{(m - n) + (m' - n')} \text{ and}$$

$\dfrac{t-m}{(m-n)+(m'-n')}$ when $x = x_n =$ zero, and $x = (t'-m') = x_m$, respectively.

The limits of the value of the factor for the surface $(t'-n')$ are $\dfrac{(t-m)+(n'-m')}{(n-m)+(n'-m')}$ and $\dfrac{(t-m)+(t'-m')}{(n-m)+(n'-m')}$ for $x = (t'\text{-}n') = x_m$ and $x = x_n =$ zero, respectively. The two last mentioned factors are used with (4), (a) being equal to $(t\text{-}t')$.

There are certain other cases which arise which can only be met by the introduction of a proportional M. M. F. factor into the differential of (5), (6) and (7). Such a case is well illustrated by a determination of the leakage flux ordinate of the curve E at the point (f), Fig. 5. The summation over the surface $(s'\text{-}r'\text{-}o')$ is easily effected from (f) by applying (1) and doubling the result. The summation over the surface $(o'\text{-}p')$ is effected by applying (3) in connection with (12). The summation over $(s'\text{-}n')$ is obtained by applying (5) and doubling the result. But the summation from (f), Fig. 5, over $(n'\text{-}m')$ can only be calculated by a proper substitution in the integral of the product of (12) by the differential of (5).

Here then, we have,—

$$y = \frac{A-x}{B}\,\frac{dx}{b+\sqrt{a^2+x^2}}$$

and

$$\sum_{x_n}^{x_m} y_{(n'-m')} = \int_{x_n}^{x_m} \frac{A-x}{B}\,\frac{dx}{b+\sqrt{a^2+x^2}}$$

when $a > b$

$$= \frac{1}{B}\Big\{\,[A \text{ times formula } (5)] -$$

$$[\sqrt{a^2+x^2} - b\log_e(b+\sqrt{a^2+x^2})]\Big\}\Big[_{x_n}^{x_m}$$

$$= \frac{A}{B}\Big\{\log_e\left(\frac{x_m+\sqrt{a^2+x_m^2}}{x_n+\sqrt{a^2+x_n^2}}\right) -$$

$$\frac{2\,b}{\sqrt{a^2-b^2}}\left[\tan^{-1}\left(\frac{x_m+b+\sqrt{a^2+x^2_m}}{\sqrt{a^2-b^2}}\right)-\tan^{-1}\left(\frac{x_n+b+\sqrt{a^2+x^2_n}}{\sqrt{a^2-b^2}}\right)\right]\Bigg\}$$

$$-\left\{\frac{\sqrt{a^2+x^2_m}-\sqrt{a^2+x^2_n}}{B}-\frac{b}{B}\log_e\left(\frac{b+\sqrt{a^2+x^2_m}}{b+\sqrt{a^2+x^2_n}}\right)\right\} \quad (8)$$

when $a = b$

$$= \frac{1}{B}\Big\{ [A \text{ times formula } (6)] -$$

$$[\sqrt{a^2+x^2} - b\log_e[b+\sqrt{a^2+x^2})]\Big\}\Big[_{x_n}^{x_m}$$

$$= \frac{A}{B}\left\{\log_e\left(\frac{x_m+\sqrt{a^2+x^2_m}}{x_n+\sqrt{a^2+x^2_n}}\right)+\frac{2\,a}{x_m+a+\sqrt{a^2+x^2_m}}-\right.$$

$$\left.\frac{2\,a}{x_n+a+\sqrt{a^2+x^2_n}}\right\}-\left\{\frac{\sqrt{a^2+x^2_m}-\sqrt{a^2+x^2_n}}{B}-\right.$$

$$\left.\frac{b}{B}\log_e\left(\frac{b+\sqrt{a^2+x^2_m}}{b+\sqrt{a^2+x^2_n}}\right)\right\} \quad (9)$$

when $a < b$

$$= \frac{1}{B}\Big\{ [A \text{ times formula } (7)] -$$

$$[\sqrt{a^2+x^2} - b\log_e(b+\sqrt{a^2+x^2})]\Big\}\Big[_{x_n}^{x_m}$$

$$= \frac{A}{B}\left\{\log_e\left(\frac{x_m+\sqrt{a^2+x^2_m}}{x_n+\sqrt{a^2+x_n}}\right)-\right.$$

$$\frac{b}{\sqrt{b^2-a^2}}\log_e\left[\left(\frac{x_m+\sqrt{a^2+x^2_m}+b-\sqrt{b^2-a^2}}{x_m+\sqrt{a^2+x^2_m}+b+\sqrt{b^2-a^2}}\right)\right.$$

$$\left.\left.\left(\frac{x_n+\sqrt{a^2+x^2_n}+b+\sqrt{b^2-a^2}}{x_n+\sqrt{a^2+x^2_n}+b-\sqrt{b^2-a^2}}\right)\right]\right\}-$$

$$\left\{\frac{\sqrt{a^2+x_m}-\sqrt{a^2+x^2_n}}{B}-\frac{b}{B}\log_e\left(\frac{b+\sqrt{a^2+x^2_m}}{b+\sqrt{a^2+x^2_n}}\right)\right\} \quad (10)$$

Now, since in the case of the point (f) considered, (b) = (f–s) and is therefore less than (a) = (s–s'), formula (8) is used; and by putting $A = (2\,x_{\mathrm{m}} - x_{\mathrm{n}})$, $B = (x_{\mathrm{m}} - x_{\mathrm{n}})$, $x_{\mathrm{m}} = (s' - m')$ and $x_{\mathrm{n}} = (s' - n')$ in (8) and solving, the value of $[y_{\mathrm{n'-m'}}]$, for (f) of Fig. 5, is readily found.

Finally, therefore, the ordinate (f–f') of curve E, Fig. 5, equals

$$(f - f') = \sum_{x_{\mathrm{n}}}^{x_{\mathrm{m}}} (2\,y_{(\mathrm{s'-r'-o'})} + y_{(\mathrm{o'-p'})} + 2\,y_{(\mathrm{s'-n'})} + y_{(\mathrm{n'-m'})}) \quad (15)$$

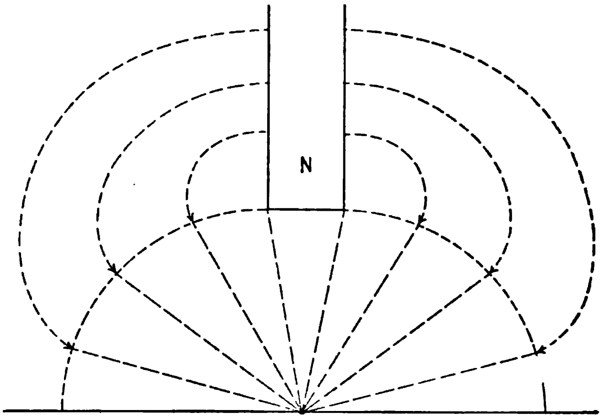


Fig. 8.

It has been pointed out (see page 688) that, to obtain the flux distribution over the side and bottom surfaces of slots, a contraction co-efficient must be entered as a factor in the final evaluation of the reciprocal summation of all points lying within such slots. This co-efficient is given a value that is proportional to the reduction which the slot imposes upon the approach to a point in the slot from the pole. If a point is taken on a smooth armature surface the width of the approach from any surface that is (r) units distant above the point is ($\pi\, r + k$), where (k) is the width of the surface at the distance (r) above the point. That this assumption is justified is shown by a consideration of Fig. 8. But if a point, as point (g), Fig. 7, is taken at the bottom of a slot which has a depth (r) and a width (k), the approach to the point at a distance (r) from the point has now a width of only (k); and since all the lines of force which pass from the pole to the point (g) have to pass between the edges of the slot opening, the slot diminishes the approach to the point in ratio of (k) to ($\pi r + k$).

In making calculations for the intensity of the flux entering the surface points of the slot, the contraction coefficient is given the form

$$\text{contraction coefficient} = \frac{k}{\pi r + k} \qquad (16)$$

in which (r) is the distance that the point in the slot is from the top of the slot, and (k) is the least width of the slot between the point considered and the top of the slot.

The proportional flux density at the point (g) of Fig. 7 is, therefore, equal to

$$\beta_g = \frac{(t - t')}{\pi (f - f') + (t - t')} \sum_{x_n}^{x_m} \Big(2 \,[y_{u-v} \text{ by } (2)] +$$

$$2 \,[y_{v-r} \text{ by } (7)] + 2 \,[y_{r-o} \text{ by } (1)] + 2 \,[y_{o-p} \text{ by } (3)] \Big) \qquad (17)$$

in so far as the presence of the one pole influences the point.

When integrating to obtain the flux intensities at the pole face where the armature surface is slotted, the summation from the top surfaces of the teeth is obtained just as the surface summation for curve D of Fig. 4 was obtained. When the integration is carried to the sides and bottoms of the slots, however, variable contraction coefficients must be introduced which have the general form of the proportional M. M. F. factors discussed in connection with (12). For instance, if it is desired to obtain the summation at point (v), Fig. 7, from the surface (f-f') of the side of the slot, a contraction coefficient must be applied to the differential of formula (2) that has a value of

$$\frac{(t - t')}{(t - t')} = 1, \text{ when } y = \frac{1}{(u - f)} \qquad (18)$$

and a value of

$$\frac{(t - t')}{\pi (f' - f'') + (t - t')}, \text{ when } y = \frac{1}{(u - f'')} \qquad (19)$$

Therefore put

$$\frac{A - x_n}{B} = 1$$

and

$$\frac{A - x_m}{B} = \frac{(t - t')}{\pi(f - f') + (t - t')},$$

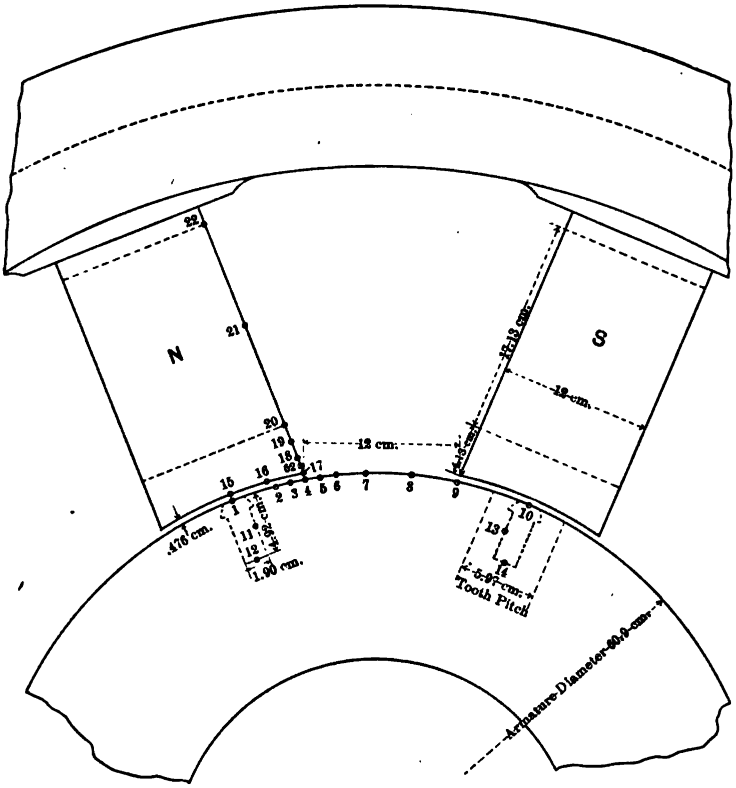


FIG. 9.

solve for the values of A and B and substitute them in (4). Then (4) applied to the case in hand will give the reciprocal summation at (u) covering the surface (f-f'). Other points on the pole face relatively to other surfaces in the slots must be treated substantially in the same manner.

PRACTICAL APPLICATION.

In illustrating the practical application of the method that has been discussed to the determination of the flux distribution in dynamo machines, I will take as a subject for discussion the 8–50–900–1150, two-phase alternator which was briefly referred to in the paper[1] read at the Omaha meeting. This machine is well suited to test the practical utility of such calculations, as it is representative of modern practice in alternator design. Furthermore, as the ratio of the circumferential width of one of its poles to the length of the pole taken parallel to the shaft is as one is to two, a fair approximation to the assumptions made on page 679 are obtained in the plane which cuts through the center lines of the pole faces at right angles to the shaft of the machine.

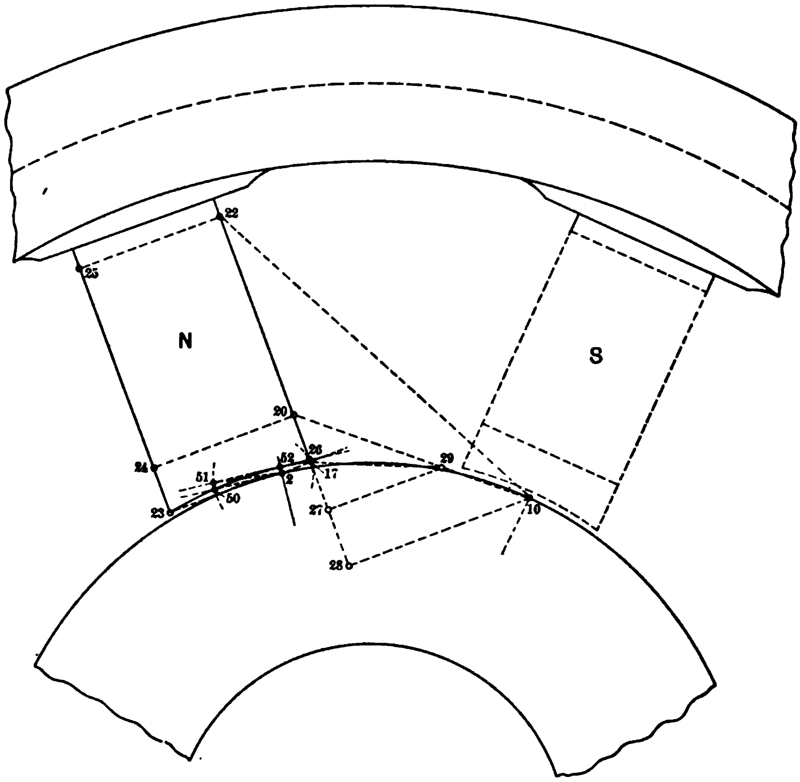


Fig. 10.

---

[1] The calculations reported at the Omaha meeting in so far as they refer to this generator are not carried out with the refinement that is here introduced, and are not therefore exact in anything like the same measure. The approximate methods there discussed were the only ones used, whereas every refinement that is mentioned in this paper has been applied in the present case.

An outline of a part of the field ring and armature of the generator is given in Fig. 9, together with the principal dimensions. The small numbered circles show the positions of the points for which the field intensities have been calculated. The number of points taken, twenty-three in all, amply provide for the complete exploration of the magnetic circuit, and their location is an indication of the sections to which it is most important to devote attention.

In determining the armature surface distribution curve, similar to the one shown in Fig. 2, measurements were taken as indicated in Fig. 10, in which the exact location is shown of every measurement needed to find the proportional flux density at points (2) and (10). By reference to the Table (1) the lengths of the construction lines shown in Fig. 10, can be obtained, and the calculations checked, if it is desired. The table and figures are presented simply with a view of making such calculations less tedious to persons wishing to employ them in other cases. By having a working model before one, a direct application in other cases is more readily followed out.

Referring specifically to point (2),

line (2)-(52) = .476 centimetres
“ (52)-(26) 2.41 “
“ (2)-(17) = 2.46 “
“ (2)-(17)-(20) = 6.59 “
“ (2)-(17)-(22) = 23.72 “
“ (52)-(51) = 5.83 “
“ (2)-(50) = 5.37 “
“ (2)-(23)-(24) = 13.73 “
“ (2)-(23)-(25) = 30.86 “

Here it may be well to note that in order to more accurately apply formula (2) to the summation over line (50)-(52), an arc was described from point (2) as a center, with a radius equal to (2)-(50), cutting line (51)-(52), [which is at right angles to line (2)-(52), drawn through (2) and the center of the armature] at (51). Line (52)-(51) was then put equal to (x_m) in formula (2), instead of either line (2)-(50) or (52)-(50).

The same construction was used in obtaining the length (52)-(26), the line (2)-(17) being the radius in this case.

The data given for the treatment of point (10) can also be readily understood by following the graphical construction of Fig. 10. In this case

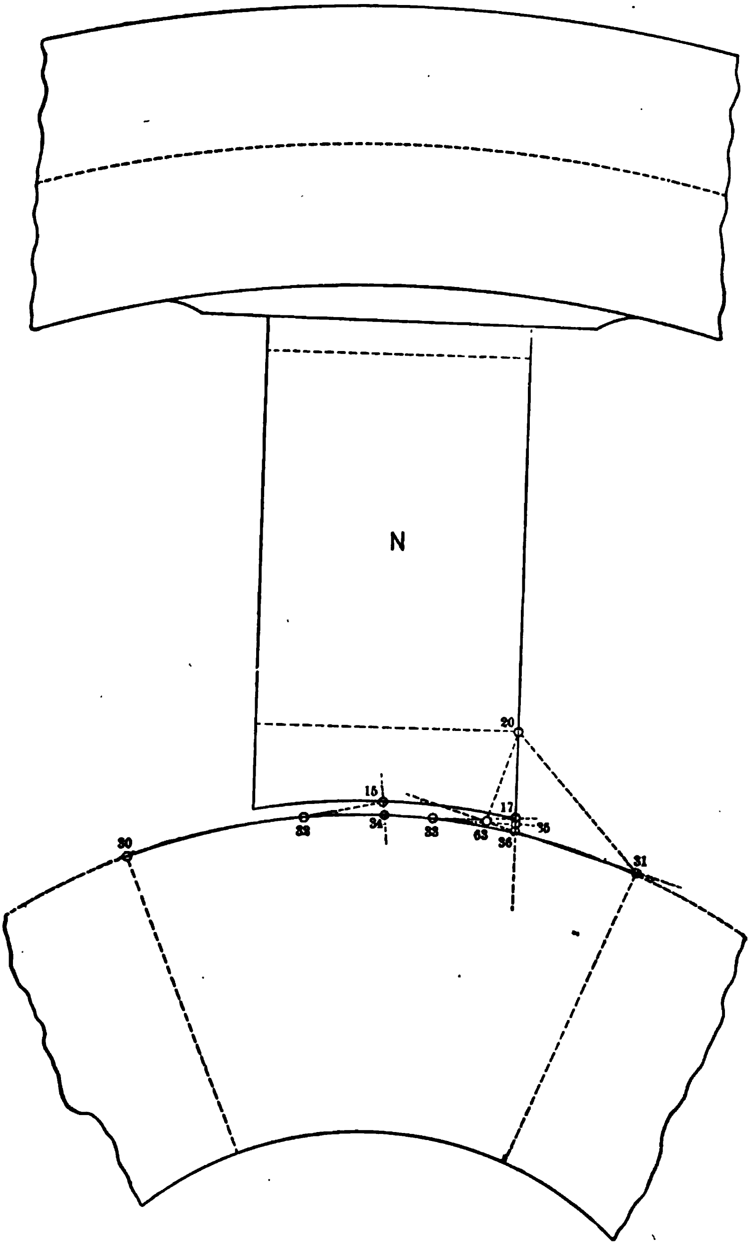


Fig. 11.

line (27)-(29) = 9.80 centimetres
" (29)-(10) = 7.40 "
" (27)-(17) = 4.06 "
" (27)-(20) = 8.20 "
" (10)-(28) = 15.50 "
" (28)-(20) = 12.95 "
" (28)-(22) = 30.08 "
" (10)-(29)-(17) = 18.00 "
" (10)-(29)-(2)-(28)-(24) = 34.18 "
" (10)-(29)-(2)-(28)-(25) = 51.26 "

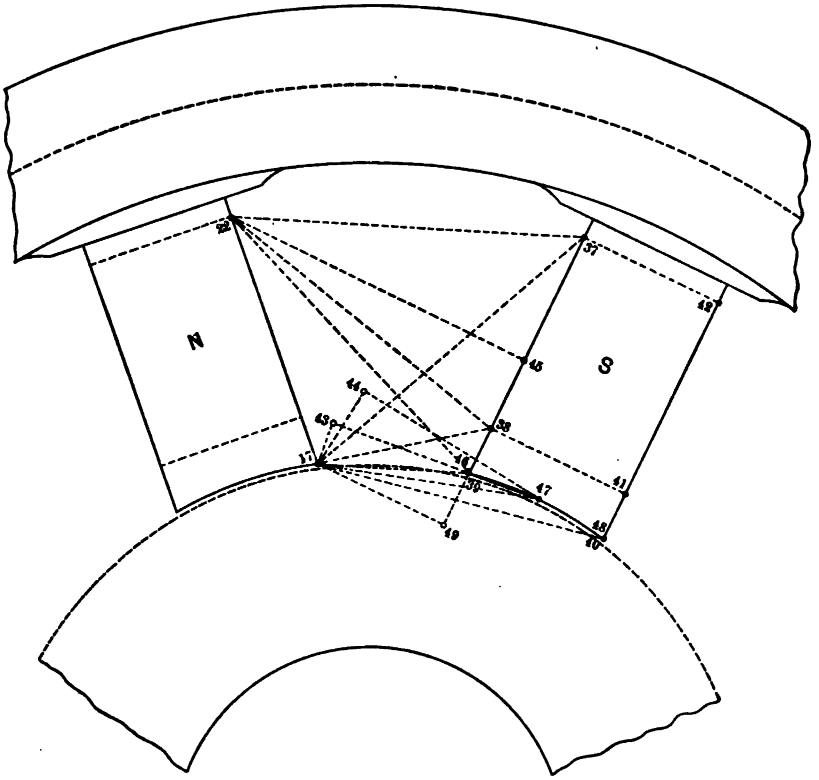


FIG. 12.

It is perfectly proper to produce constructions into the armature core and pole pieces, and take measurements therefrom so long as none of the distance lines, such as line (10)-(29)-(17), which are included in a summation fall materially inside of the boundaries of such portions of the iron part of the machine as are depended upon for the data. For this reason it is advisable to use formula (5) as illustrated, in getting the summation over the surface (17)–(20), instead of using formula (2) and putting the distance (10)–(28)=(a) and the distances (28)–(17) and (28)–(20) respectively equal to (x_n) and (x_m) for such a summation. The latter procedure would require the first distance line to pass directly from (10) to (17), and thereby cut into a surface, all points of which are taken as being at a constant potential. Theoretically this is an impossibility.

In Fig. 10 the S pole is shown by a dotted line, as it is supposed to be removed at the time the data for the single pole armature distribution curve A is being determined.

The results of the summations for which the data is given in the first section of Table 1, are tabulated in the left hand column of the table. The partial summations (a, b and c), in the case of point (1), are doubled in obtaining the total, as the point being symmetrical with the pole it was only necessary to take the summations over one of the two symmetrical parts of the pole perimeter lying on either side of point (1).

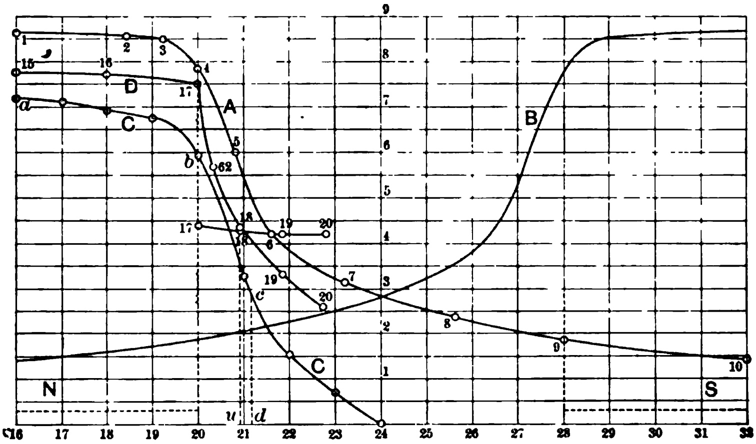


FIG. 13.

Plotting the "totals" of points from (1) to (10) of Table 1, opposite properly spaced ground line divisions the curve A of Fig. 13 is obtained. As the data also suffices for plotting curve B of Fig. 13, which shows the field due to the S pole, it also appears. Subtracting the ordinates of curve B from those of curve A, curve C, Fig. 13 results, and shows the actual variations in the strength of the magnetic field along the surface of the armature, when there are no slots cut in the armature surface. Or, if there

TABLE I, SECTION 1.

SINGLE POLE ARMATURE SURFACE DISTRIBUTION CURVE DATA.

Number of figure from which data was obtained	Number of point from which summation is taken.	Data designation letter for separate integrations.	a	b	x_n	x_m	Number of formula used in integrating.	Partial and total summation values.
		a	.476	0	0	6.05	2	3.241
	1	b	0	0	6.05	10.18	1	.518
		c	0	0	10.18	27.31	3	.581
		total						8.680
		a	.476	0	0	2.41	2	2.315
10	2	b	0	0	2.46	6.59	1	.986
		c	0	0	6.59	23.72	3	.770
		d	.476	0	0	5.33	2	3.110
		e	0	0	5.37	13.73	1	.940
		f	0	0	13.73	30.86	3	.460
		total						8.581
		a	.476	0	0	1.22	2	1.634
	3	b	0	0	1.30	5.43	1	1.431
		c	0	0	5.43	22.56	3	.880
		d	.476	0	0	5.33	2	3.110
		e	0	0	5.37	14.73	1	1.00,
		f	0	0	14.73	31.86	3	.436
		total						8.504
		a	0	0	.476	4.61	1	2.272
	4	b	0	0	4.61	21.74	3	.972
		c	.476	0	0.	5.33	2	3.110
		d	0	0	5 37	15.93	1	1.087
		e	0	0	15.93	33.06	3	.414
		total						7.855
		a	.455	0	1.2	5.42	2	1.510
	5	b	1.06	0	.72	4.85	2	2.038
		c	1.06	0	4.85	21.98	4	.920
		d	0	0	5.45	17.13	1	1.145
		e	0	0	17.13	34.26	3	.380
		total						5.993
		a	.37	0	2.42	5.42	2	.802
	6	b	2 22	0	1.73	5.86	2	1.000
		c	2.22	0	5.86	22.99	4	.834
		d	0	0	5.45	18.33	1	1.212
		e	0	0	18.33	35.46	3	.364
		total						4.212
		a	4.50	0	1.75	5.87	2	.703
	7	b	4.50	0	5.87	23.00	4	.646
		c	.1	0	4.82	20.73	2	1.458
		d	0	0	20 73	37.86	3	.334
		total						3.141
		a	7.76	0	3.16	7.29	2	.438
	8	b	7.76	0	7.29	24.42	4	.590
		c	0	0	8.40	24.23	1	1.058
		d	0	0	24.23	41.36	3	.290
		total						2.376
		a	10.86	0	5.00	9.13	2	.316
	9	b	10.86	0	9.13	26.26	4	.480
		c	0	0	12.00	27.88	1	.841
		d	0	0	27.88	45.01	3	.250
		total						1.887
		a	9.80	7.40	4.06	8.20	5	.220
		b	15.50	0	12.95	30.08	4	.350
10	10	c	0	0	18.00	34.13	1	.636
		d	0	0	34.13	51.26	3	.210
		total						1.416

NOTE: Point No. 1, being symmetrically placed with reference to pole N, the summation is only taken over half the polar surface. Values a, b and c, must therefore be doubled to obtain the "total."

TABLE I, SECTION 2.

Pole Face Density Distribution Curve Data.

Number of figure from which data was obtained	Number of point from which summation is taken.	Data designation letter for separate integrations.	a	b	x_n	x	Number of formula used in integration.	Partial and total summation values.
11	15	a	.476	0	0	3.61	2	2.721
		b	0	0	3.69	12.00	1	1.180
		total						7.802
	16	a	.476	0	0	3.61	2	5.442
		b	0	0	3.69	9.00	1	.891
		c	0	0	3.69	15.00	1	1.403
		total						7.736
	17	a	.476	0	0	3.61	2	5.442
		b	0	0	3.69	6.00	1	.488
		c	0	0	3.69	18.00	1	1.585
		total						7.515
	62	a	.86	0	.17	6.16	2	2.352
		b	.476	.476	0	3.61	6	1.838
		c	0	0	4.17	18.48	1	1.488
		total						5.678
	18	a	1.72	0	.41	6.40	2	1.790
		b	.476	1.377	0	3.61	7	1.223
		c	0	0	5.07	19.38	1	1.341
		total						4.354
	19	a	3.03	0	.83	6.80	2	1.279
		b	.476	2.753	0	3.61	7	.850
		c	0	0	6.44	20.75	1	1.170
		total						3.299
11	20	a	4.33	0	1.20	7.16	2	.963
		b	.476	4.13	0	3.61	7	.572
		c	0	0	7.82	22.13	1	1.041
		total						2.576

Note: Point No. 11, being symmetrically placed with reference to pole N, the summation is only taken over half the polar surface.

TABLE I, SECTION 3.

Leakage Field Distribution Curve Data.

12	17	a	11.15	0	4.00	8.73	2	.316
		b	11.15	0	8.73	25.86	4	1.338
		c	3.56	0	11.55	17.55	2	.406
		d	7.92	0	16.50	22.50	2	.286
		e	0	0	23.60	27.70	1	.157
		f	0	0	27.70	40.80	3	.743
		total						4.411
	18	a	12.13	0	3.61	7.74	2	.293
		b	12.13	0	7.74	24.87	4	1.315
		c	2.50	0	12.40	18.40	2	.385
		d	6.04	0	17.60	23.60	2	.297
		e	0	0	24.40	28.50	1	.157
		f	0	0	28.50	45.60	3	.725
		total						4.304
	19	a	13.10	0	2.68	6.81	2	.288
		b	13.10	0	0.81	23.94	4	1.349
		c	0	0	13.30	29.40	1	.793
		d	0	0	29.40	46.50	3	.697
		total						4.208
	20	a	14.07	0	1.70	5.83	2	.281
		b	14.07	0	5.83	22.96	4	1.417
		c	0	0	14.10	30.30	1	.765
		d	0	0	30.30	47.40	3	.694
		total						4.203
	21	a	20.20	0	0	4.42	2	.214
		b	20.20	0	0	16.90	4	.779
		c	0	0	20.60	36.80	1	.578
		d	0	0	36.80	53.90	3	.396
		total						2.363
12	22	a	26.20	0	0	10.80	4	.128
		b	26.20	0	0	6.30	4	.197
		c	26.20	0	6.30	10.40	2	.147
		d	0	0	28.20	44.40	1	.449
		e	0	0	44.40	61.50	3	.170
		total						1.091

are slots in the armature surface, it shows the flux intensities at the tops of the teeth, by projecting them up to the curve, in

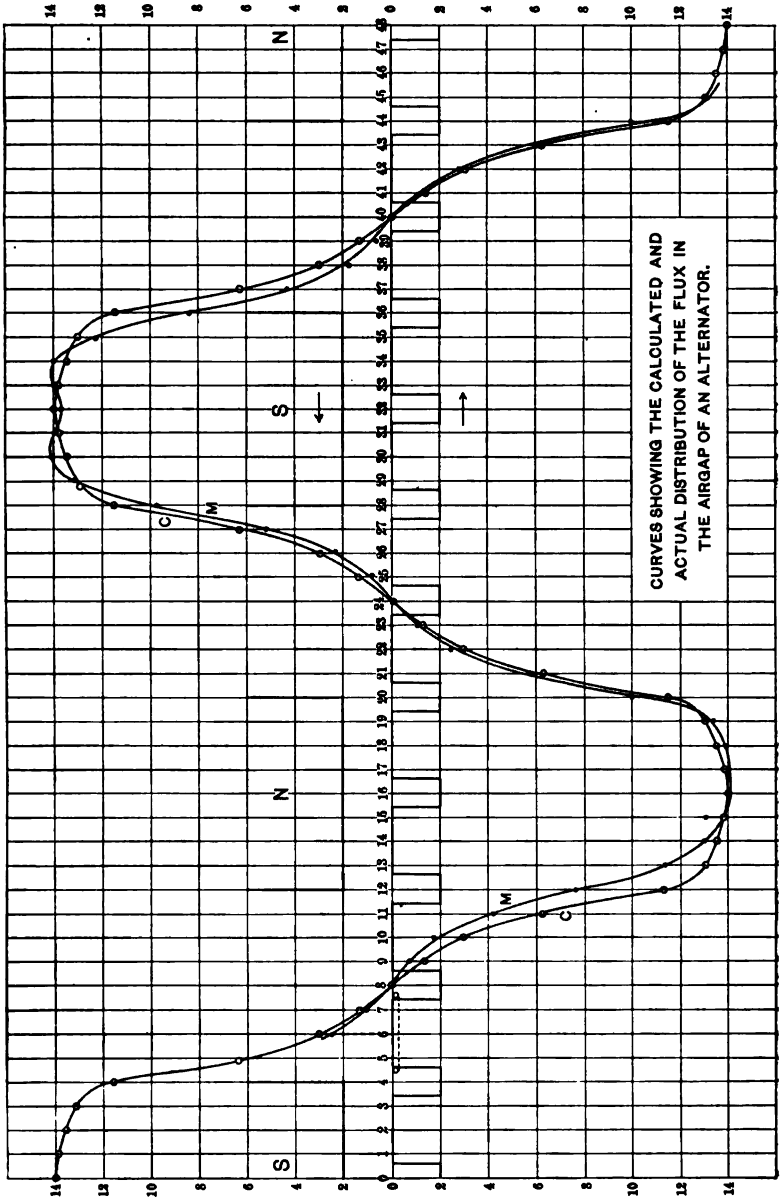


FIG. 14.

whatever positions they may be. A complete cycle of the armature surface density curve c is shown in Fig. 14.

Fig. 11 shows the graphical constructions for obtaining data for the pole face density ordinates at points (15) and (20). As in the case of curve D of Fig. 4, the summation here is taken over only the pole pitch distance (30)-(31), as this summation gives the actual pole face density distribution curve corresponding to the armature surface density curve C. The data for points on the pole face density curve is recorded in the second section of Table 1, and was obtained from the drawings as follows:

In the case of point 15, located at the center of the pole face,

line (15)-(34) — .476 centimetres
" (34)-(32) — 3.610 "
" (15)-(32) — 3.69 "
" (15)-(30) — 12.00 "

The results obtained by the two operations (*a*) and (*b*), are each taken twice in obtaining the total summation for point (15).

In the case of point 20,

line (20)-(63) — 4.33 centimetres
" (63)-(36) — 1.20 "
" (63)-(31) — 7.16 "
" (17)-(36) — .476 "
" (20)-(17) — 4.13 "
" (36)-(33) — 3.61 "
" (20)-(17)-(33) — 7.82 "
" (20)-(17)-(30) — 22.13 "

With these statements, connecting the data with the figure, the calculations for these two points will be readily followed. The data for the other points (16), (17), (62), (18) and (19), see Fig. 9, was obtained in a similar way.

From the record of the "totals" in the left hand column of the second section of Table 1, the curve D of Fig. 13, has been plotted relatively to properly spaced points of the pole face and tips developed along the base line. It will be noticed that this curve is more nearly flat topped than curve C, and that after the pole corners are passed the curve drops *very* suddenly. This form of distribution over the face and corners of the pole is what we would expect, and the result is thoroughly in accord with the usual assumption in air-gap calculations. It remains to be seen, however, how much of the pole tip flux finds its way into the armature.

To determine this the area (15)-(*a*)-(*b*)-(17)-(16)-(15) between the tops of curves C and D was integrated. Then the section

(24)-(*c*)-(*d*)-(24) was laid off equal in area to (15)-(*a*)-(*b*)-(17)-(16)-(15), and the area (*b*)-(*c*)-(*d*)-(20)-(*b*) integrated. Finally, when the area (17)-(62)-(18)-(*u*)-(20)-(*b*)-(17) was laid off equal in area to (*b*)-(*c*)-(*d*)-(20)-(*b*), the point (18) on curve D was located, beyond which no flux enters the armature, since the pole face flux area (15)-(17)-(18)-(*u*)-(16)-(15) is equal to the area of the armature surface flux area (*a*)-(*b*)-(*c*)-(24)-(16)-(*a*). The point on the pole at which the lines of force cease to enter the armature from the pole is then the point (18) of Fig. 9.

When the leakage field is estimated the armature should be removed, and it is therefore shown as a dotted line in Fig. 12, as from this figure is obtained the data for the proportional leakage field ordinates recorded in the third section of Table 1.

The summation diagrams for two points, (17) and (22), are shown; referring to the table and the figure we find that for (17)-

the line (17)-(49) — 11.15 centimetres
" (49)-(39) — 4.60 "
" (49)-(38) — 8.78 "
" (49)-(37) — 25.86 "
" (17)-(43) — 3.56 "
" (43)-(46) — 11.55 "
" (43)-(47) — 17.55 "
" (17)-(44) — 7.92 "
" (44)-(47) — 16.50 "
" (44)-(48) — 22.50 "
" (17)-(40) — 23.36 "
" (17)-(40)-(41) — 27.70 "
" (17)-(40)-(42) — 44.80 "

The proportional flux multiplier used in connection with partial summations (*b*) and (*f*), point (17), and to be applied in equations (4) and (3), has the form

$$\frac{2\,x_m - x_n - x}{x_m - x_n}.$$

In the case of point (22),

line (22)-(45) — 26.2 centimetres
" (45)-(37) — 10.8 "
" (45)-(38) — 6.3 "
" (45)-(39) — 10.4 "
" (22)-(39) — 28.2 "
" (22)-(39)-(40)-(41) — 44.4 "
" (22)-(39)-(40)-(42) — 61.5 "

In the case of point (22) and the summation (45)-(37), since the proportional potential between points (22) and (45) is equal to

$$\frac{\text{line }(37)\text{–}(45)}{\text{line }(37)\text{–}(38)} = .68$$

and the potential between points (22) and (37) is zero, the constants of the correct proportional M. M. F. factor have the following values:

$$A = x_m \text{ and } B = 1.588\, x_m$$

Again, since the proportional difference of potential between point (22) and (38) is one, in the summation over the surface (45)-(38),

$$A = 1.703\, x_m \text{ and } B = 2.703\, x_m.$$

The proportional leakage field ordinates tabulated in the third section of Table 1, for the points (17,) (18), (19) and (20) are plotted over properly spaced divisions on the base line of Fig. 13. It is seen that the curve E determined in this way crosses the curve D very nearly at the point where the pole face flux ceases to flow into the armature. This checks the first calculations, as of necessity there must be the same density on either side of the point on the pole tip at which the flux divides to pass to the armature and the adjacent pole respectively.

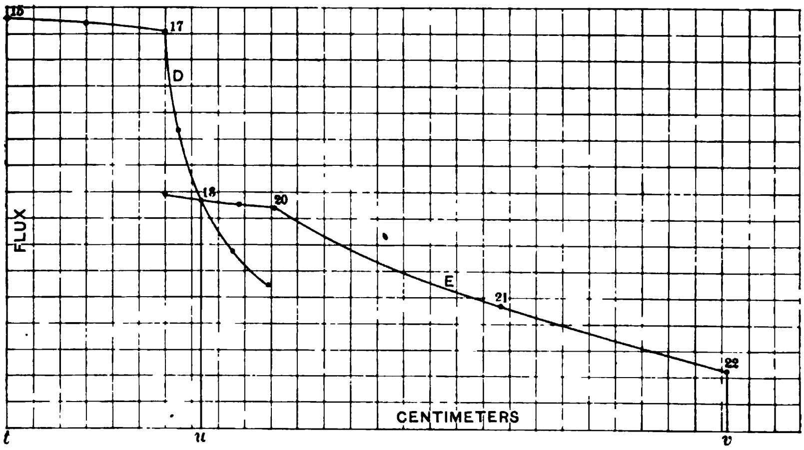


FIG. 15.

To determine the leakage co-efficient of the machine, approximately, we can plot the results contained in the second and third sections of Table 1, and by integrating the areas they enclose obtain the necessary data. Fig. 15 shows the result of this plot.

The area of (15)-(17)-(18)-(*u*)-(*t*)-(15) is 6.7 units, and the area of (18)-(20)-(21)-(22)-(*v*)-(*u*)-(18) is 6.6 units, therefore the leakage co-efficient is approximately

$$\lambda = \frac{6.7 + 6.6}{6.7} = 1.98$$

Experimental Results.

We have now arrived at a point at which we can profitably review certain of the experimental results that have been obtained. The experiments were performed during the spring of the present year by Messrs. Nathan Kohn and L. S. Arnot,[1] and the records made by them bear every evidence of painstaking care. One set of readings which they obtained shows the amount of flux which enters the top of a tooth when the tooth is placed in

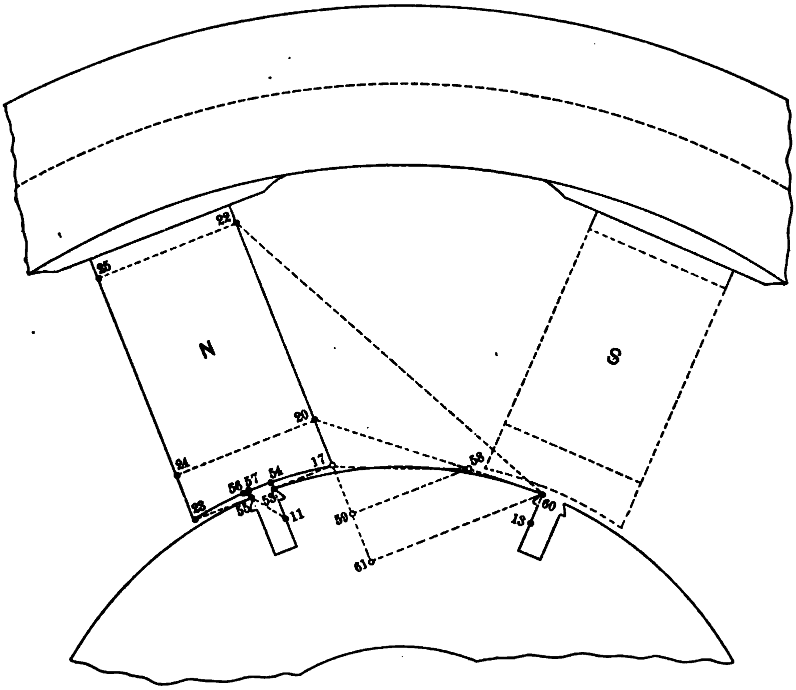


Fig. 16.

---

[1] "Special Investigation of the Characteristics of the Monocyclic Generator," a Thesis presented to the Faculty of Purdue University by Leroy S. Arnot and Nathan Kohn, for the Degree of Bachelor of Science in Electrical Engineering, June, 1900.

TABLE I, SECTION 4.

SLOT FLUX INTENSITY DISTRIBUTION CURVE DATA.

Number of figure from which data was obtained	Number of point from which summation is taken.	Data designation letter for separate integrations.	a	b	x_n	x_m	Number of formula used in integration.	Partial and total summation values.
16	11	a	3.02	0	0	2.25	2	.689
		b	.476	2.54	0	5.10	7	1.011
		c	0	0	7.64	11.77	1	.431
		d	0	0	11.77	28.90	3	.517
		e	.476	3.17	.35	5.10	7	.820
		f	0	0	8.27	12.40	1	.405
		g	0	0	12.40	29.53	3	.500
		total						4.373
	12	a	5.39	0	0	1.05	2	.198
		b	0	0	10.05	14.18	1	.343
		c	0	0	14.18	31.31	3	.450
		d	.476	5.00	.10	5.10	7	1.057
		total						4.096
16	13	a	10.05	8.79	4.12	8.25	5	.207
		b	14.90	2.54	12.30	29.40	8	.333
		c	0	0	19.64	35.80	1	.604
		d	0	0	35.80	52.90	3	.210
		total						1.354
	14	a	10.05	11.26	4.12	8.25	7	.190
		b	14.90	5.00	12.30	29.40	8	.302
		c	0	0	22.10	38.30	1	.348
		d	0	0	38.30	55.40	3	.194
		total						1.234

Note: Point No. 12, being symmetrically placed with reference to pole N, the summation is only aken over half the polar surface.

Contraction coefficient for point No. 11 and point No. 13 is .191.
Contraction coefficient for point No. 12 and point No. 14 is .108.
See page 719.

TABLE II.

DATA FOR PLOTTING CURVE M., FIG. 14, AND CURVE N., FIG. 18.

Position of Exploring Coil.	Values given by exploring coil around tooth.	Values given by exploring coil in slot.	Position of exploring coil.	Values given by exploring coil around tooth.	Values given by exploring coil in slot.
6	245000		27	534900	28600
7	102600		28	969800	163500
8	17580		29	1322200	215880
9	73000		30	1416400	232988
10	167000		31	1400840	242660
11	422600		32	1372700	255560
12	769400		33	1403600	265000
13	1128600		34	1403600	276670
14	1293600		35	1217300	299932
15	1307100		36	835600	238800
16	1408400		37	441275	127000
17	1400800		38	176200	80000
18	1392100		39	68000	62000
19	1351330		40	11800	40900
20	1033800		41	113100	26230
21	588300		42	269800	4460
22	247500	56400	43	622200	58000
23	109600	40690	44	1007670	193650
24	524	21500	45	1322200	209500
25	77700	9700	46		224050
26	223800	6300	47		238800

various positions relatively to the pole. The data for this set is tabulated in the center column of Table 2, and is plotted in Fig 14, being shown as the curve M. In this figure we have then a comparison between carefully calculated and carefully explored armature surface flux distribution curves. The curves follow one another with remarkable accuracy, the variations between them at the positive and negative crests where they depart most from one another, being but between two and three per cent. even in the case of the points at plotting position 30, Fig. 14.

Regarding curve M the experimenters say: "The readings obtained are very symmetrical relatively to the poles. There is a slight tendency to draw toward the pole in the direction in which the armature is moved. The indentation at the apex of the second curve could be due to a sudden variation in the length of the air-gaps, or a point of low permeance in the iron of the pole face."

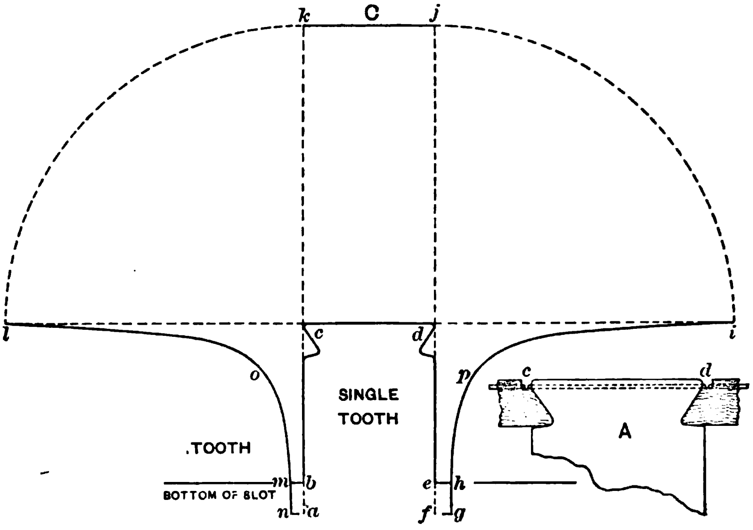


FIG. 17.

In Fig. 18 is shown the plot of the data in the left hand column of Table 2. Its ordinates are proportional to the flux entering a slot as the armature is moved under the poles. "The curve has a very good symmetry. The zero points of the curve are, however, very much drawn in the direction of motion of the armature. This is due to the residual magnetism which the iron retains while leaving the fringing field, and it is necessary to move the slots some distance into the opposite fringing field before the residual magnetism is counteracted and the polarity of the iron in the slot reversed."

Curves M, Fig. 14, and N, Fig. 18, were obtained by winding exploring coils around a tooth and in a slot as indicated, and using a ballistic galvanometer method. The current in the field circuit was reversed by a quick-acting switch several times in making the record for each reading, and the average results taken. The ordinates of the curve M represent accurately the amount of flux entering the top of a tooth, but the ordinates of the curve N are thought to be a few per cent. smaller than the actual values as some difficulty was experienced in getting the slot coil to hug the sides of the teeth closely. As the density on the side faces of the teeth diminish very rapidly from the corner of the tooth downward, a very slight opening between the sides of the coil and the edges of the teeth would reduce the deflection given by the coil considerably below the normal.

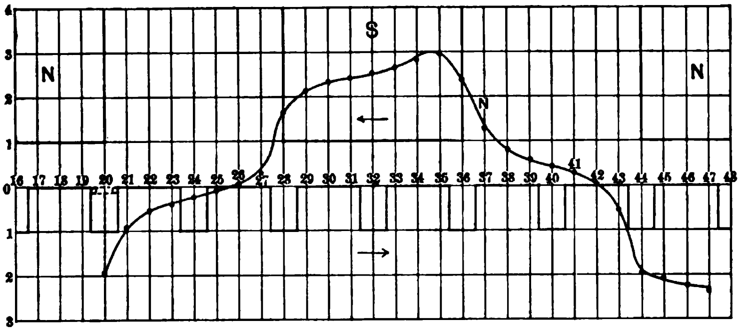


FIG. 18.

However this may be, the results show that in the maximum positions a slot takes actually 21 per cent. as much flux as the face of a tooth, or proportionally 46 per cent. of the flux, as a tooth is 2.2 times as wide as a slot.

The experimenters also record the data for curves O and P plotted in Figs. 19 and 20 respectively. Curve O of Fig. 19 is plotted from the data tabulated in the center column of Table 3. The data was obtained by using a complete phase winding as an exploring coil. Curve P of Fig. 20, was plotted from data re-

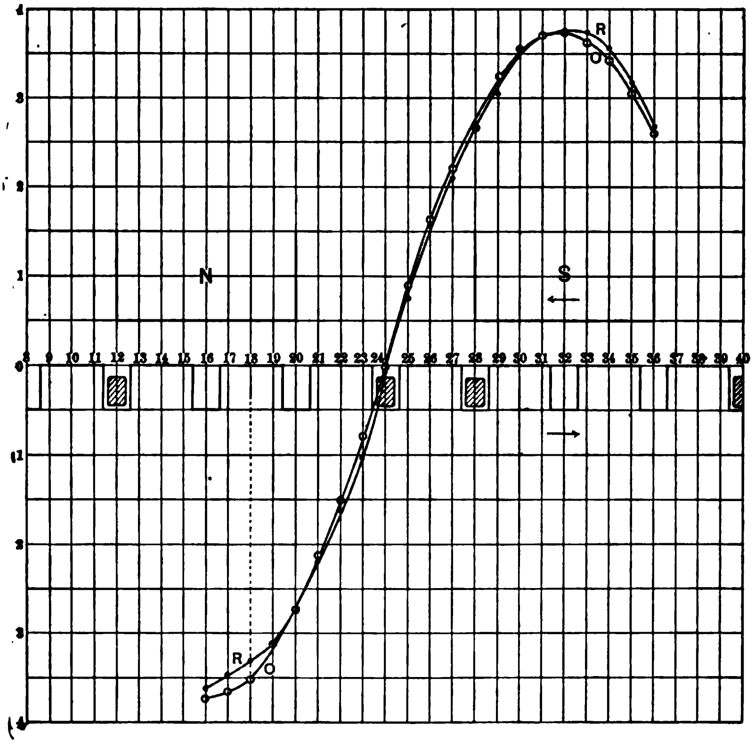


Fig. 19.

TABLE III.

Data for Plotting Curves in O and R, Fig. 19.

Position of exploring coil.	Values given by armature winding.	Values integrated from data in table 2.	Position of exploring coil.	Values given by armature winding.	Values integrated from data in table 2.
16	3744000	3645000	28	2680000	2692000
17	3672000	3466000	29	3257000	3048000
18	3524000	3322000	30	3572000	3571000
19	3120000	3111000	31	3701000	3692000
20	2740000	2773000	32	3781000	3731000
21	2118000	2214000	33	3624000	3755000
22	1506000	1629000	34	3440000	3592000
23	776000	1015000	35	3022000	3199000
24	7000	74000	36	2606000	2695000
25	918000	764000			
26	1655000	1567000			
27	[illegible]	2117000			

corded in the center column of Table 4. This data was obtained by placing an exploring coil on the armature as indicated; the coil covers an area equal to the polar pitch multiplied by the length of the armature.

To check the results of the experimenters I have derived from their single tooth and slot data tabulated in Table 2, the data necessary for plotting integrated flux curves. Summing up the tooth and slot values corresponding to the successive positions occupied by the teeth and slots which are enclosed in an armature coil, the data in the left hand column of Table 3 is obtained. This data, plotted in Fig. 19, shows that the integrated curve R checks the complete phase winding curve O very nicely.

Similarly summing up the tooth and slot values corresponding to the successive positions occupied by the teeth and slots which are embraced by the pole pitch exploring coil, shown in Fig. 20, the data in the left-hand column of Table 4 is obtained. This data plotted in Fig. 20 gives the curve S, which checks the curve P almost as accurately as the curve R checks the curve O.

In their thesis Messrs. Kohn and Arnot say, in referring to the placing of the exploring coils used by them, that "coil No. 18 is wound around a pole above a field coil," and that "coil No. 19 is wound around the same pole that No. 18 is wound on, but is located below the field coil." As the field coil on pole N of Fig. 10, occupies the space between the lines (22)-(25) and (20)-(24) the exploring coils were placed respectively just above and below the lines mentioned. They further say that "coil No. 4 is wound around four teeth and four slots." This is the exploring coil shown in Fig. 20, the data obtained with which is tabulated in Table 4. The experimenters record the following maximum readings:

Maximum for coil No. 4, 4,074,000 Maxwells.
" " " 18, 7,677,000 "
" " " 19, 5,765,000 "

From this data it appears that between the line (22)-(25) of Fig. 10 and the armature surface 3,603,000 maxwells leak away or that the machine has a leakage factor or co-efficient of 7,677,000 ÷ 4,074,000 = 1.88.

This agrees reasonably well with the calculated value of 1.98, but it should not be compared with it without modification.

In obtaining the integrated curve value of 3,918,000 maxwells, recorded in Table 4, opposite position (31), the calcula-

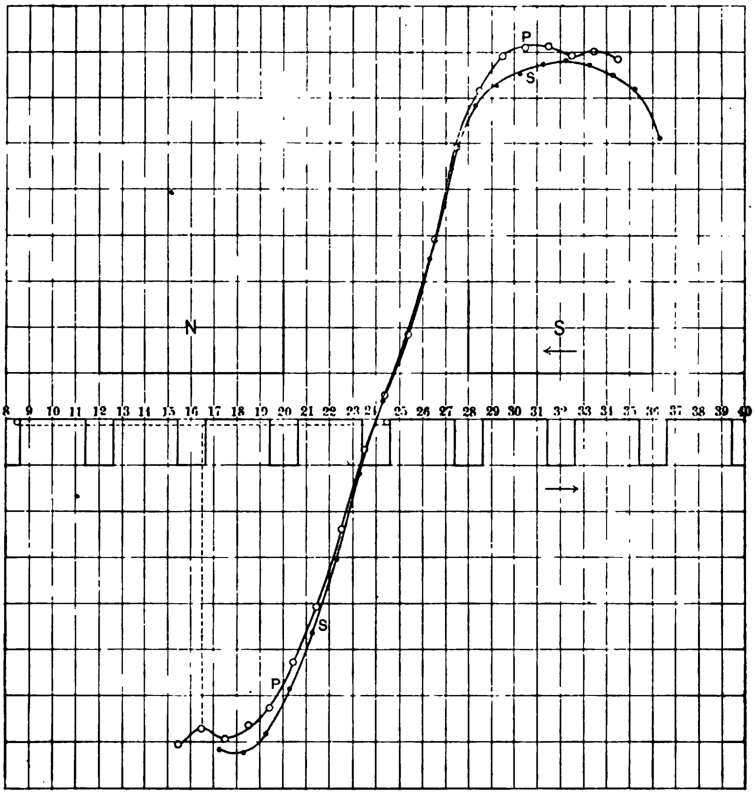


Fig. 20.

TABLE IV.

Data for Plotting Curves P and S, Fig. 20.

Position of Exploring Coil.	Values given by exploring coil.	Values integrated from data in table 2.	Position of exploring coil.	Values given by exploring coil.	Values integrated from data in table 2.
16	3523000	3595000	28	2967000	3641000
17	3349000	3605000	29	3596000	3774000
18	3479000	3403000	30	3998000	3878000
19	3305000	2927000	31	4074000	3918000
20	3131000	2309000	32	4074000	3855000
21	2635000	1502000	33	3998000	3751000
22	2042000	586000	34	4023000	3600000
23	1175000	208000	35	3923000	3068000
24	313000	852000			
25	279000	1768000			
26	935000	2745000			
27	1962000	3132000			

tions show that 3,220,000 maxwells of this flux enter through the tops of the teeth and 699,000 maxwells, through the slots. Therefore, 82.2 per cent. of the flux that enters the armature, enters by the tops of the teeth. Further, since the width of a tooth is 4.1 cm. and the width of a slot 1.9 cm., the faces of the teeth occupy only 68.3 per cent. of the armature surface. Therefore, we are approximately correct in assuming that if the machine had a smooth surfaced armature with the same air-gap clearance, coil No. 5 would give an indication, other things being the same, of

$$\frac{4{,}074{,}000 \times 82.2}{68.3} = 4{,}903{,}000 \text{ maxwells}$$

and the leakage factor would have had a value of

$$\frac{3{,}918{,}000 + 4{,}903{,}000}{4{,}903{,}000} = 1.80$$

This is a value that can more properly be compared with the calculated value[1] (1.98).

We will now pass to the consideration of calculations to determine the intensity of the flux entering the side and bottom surfaces of slots.

As an example, the flux distribution in a slot placed under the center of a pole, as shown in Fig. 16, has been calculated and the results are given in the fourth section of Table 1. The graphical construction used in obtaining the data is exhibited in Fig. 16, for the points (11) and (13).

In the case of point (11).

line (11)-(54) — 3.02 centimetres
" (54)-(56) — 2.25 "
" (53)-(54) — .476 "
" (11)-(53) — 2.54 "
" (54)-(17) — 5.10 "
" (11)-(53)-(17) — 7.64 "
" (11)-(53)-(17)-(20) — 11.77 "
" (11)-(53)-(17)-(22) — 28.90 "
" (55)-(57) — .476 "
" (11)-(55) — 3.17 "
" (57)-(56) — .35 "

---

[1] Had the more exact method for calculating the leakage outlined in the footnote on page 31 been employed in this practical case, leakage coefficient results agreeing more exactly with the experimental values would have been obtained. This was not done, as the chief value of the method is i its application to armature surface flux distribution curve calculations.

line (57)-(23) — 5.10 centimetres
" (11)-(55)-(23) — 8.27 "
" (11)-(55)-(23)-(24) — 12.40 "
" (11)-(55)-(23)-(25) — 29.53 "

In the case of point (13),

line (58)-(59) — 10.05 centimetres
" (60)-(58)-(13) — 8.79 "
" (59)-(17) 4.12 "
" (59)-(20) — 8.25 "
" (60)-(61) — 14.90 "
" (13)-(60) — 2.54 "
" (61)-(20) — 12.30 "
" (61)-(22) — 29.40 "
" (13)-(60)-(17) — 19.64 "
" (13)-(60)-(23)-(24) — 35.80 "
" (13)-(60)-(23)-(25) — 52.90 "

Since both points are at the same distance from the top of the slots, the contraction co-efficient for each is the same, and has the value

$$\text{contraction coefficient} = \frac{1.9}{\pi \times 2.54 + 1.9} = .192$$

Since the slot is 1.9 cm. wide and the point is 2.54 cm. from the top edge of the slot.

It must not be forgotten that before the "totals" tabulated in Table 1, section 4, can be used in plotting the flux distribution in a tooth, the value obtained for point (13) must be subtracted from the value obtained for point (11), and that the value for point (14) must be subtracted from point (12). This is necessary as the values for points (11) and (12) correspond to "curve A" ordinates of the slot under the N pole of Fig. 16, while the values for points (13) and (14) correspond to similarly situated ordinates of the "curve B" of the same slot under the same pole. And, as in the case of the armature surface flux distribution curves already discussed, the ordinates of the slot "A" and "B" curves must be subtracted to get the values of the ordinates of the actual slot flux distribution. These ordinates combined with the armature surface density curve ordinates corresponding to the edges (*c*) and (*d*) of the teeth bounding the slot, give, when plotted, the distribution curves shown in Fig. 17. It will be noticed that the surface density at the sides of the slots diminishes very rapidly until a point about half way down the tooth is reached, after which it falls off more slowly. When the bottom of the slot is reached, the flux density has diminished until it is only 4.2 per cent. as great as the density at the top of the tooth. Half way down the side of the tooth the density is 7.9 per cent. as great as it is at the top.

The area (*c–k–j–d–c*) is proportional to the calculated flux entering the top of a tooth, and the area (*a–b–c–l–o–m–n–a*) plus (*f–e–d–i–h–g–f*) is proportional to the calculated flux entering the armature core through a slot. Taking the ratio of the latter to the former we find that the calculated results indicate that 37 per cent. as much flux enters the armature core through the slots as through the teeth, or that 27 per cent. of the total flux enters the armature by the slots.

It has already been pointed out that if we compare the actual maximum tooth and slot values, tabulated opposite positions (33) and (35) of Table 2, the comparison shows that 21 per cent. as much flux enters by the slots as by the teeth. If we compare the tooth and slot flux values that are tabulated opposite position (35) in Table 2, *i. e.*, if we compare the value of the flux that enters the tooth when the tooth is in the position which the slot occupies when maximum flux enters the slot, with this maximum slot flux, the comparison shows that 25 per cent. as much flux enters the armature core by the slots as by the teeth.

These ratios of experimental flux values are from a half to one-third less than the ratio of the calculated values. But this does not conclusively prove that the calculated percentage is too[1]

---

[1] Messrs. Herdt and Archibald in a paper on "Conditions Affecting the Wave Form of Alternators," read before the Canadian Electrical Association, Aug. 30, 1900, show the assemblage of parts of a "revolving field distributed winding alternator" reproduced in Fig. B, and say in referring to the machine:

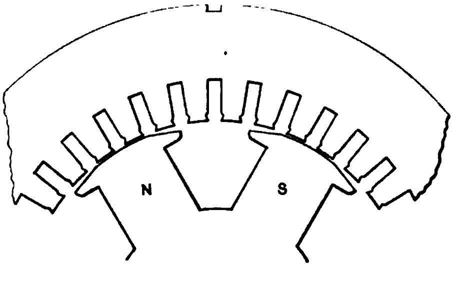


Fig. B.

"As might have been expected, the larger part of the induction enters the armature through the teeth, but about one-third, in the case of those teeth immediately opposite the pole, passes into the armature by way of the slot."

"*About one-third*," presumably, of the *total* flux.

high. The experimental results show [see Table 2, position (35)] that when a maximum of 300,000 maxwells were flowing into the slot, 1,217,000 maxwells were flowing into the tooth, and to obtain a ratio of .37 instead of .25 (the ratio these numbers give), would only require the loss of 50,000 maxwells on each side of the tooth, and a gain of a corresponding number by the coil. As it was necessary in the experiments, in order to hold the exploring coils in place, to cut the wooden slot caps as indicated at A, Fig. 17, points (*c*) and (*d*), it is quite likely that there was at least this great error in the results. The flux density changes in intensity so rapidly about the corners of the teeth that an aggregate variation of one-sixteenth of an inch in the position of the exploring coils would account for the discrepancy between the calculated and experimental results.

CONCLUSION.

This paper has been prepared for the INSTITUTE with a view to placing on record a crucial test of a method for calculating flux distribution. The general applications previously cited pointed to the probability of its giving indications quite comparable to actual conditions, and these latest results tend to substantiate such surmises. The method lends itself with almost equal readiness to the calculation of stray fields about armature ends, that it does to the calculation of inter-polar reactions, and by suitable modifications in the formulas, can be used for general electromagnetic calculations in which the law of "inverse squares" is even more nearly approximated than in the case cited.

Electrical Laboratory,
Purdue University,
December, 1900.

APPENDIX.

For the benefit of those interested in the detail of making the calculations, the full set of substitutions made in determining the complete summation of the reciprocals at the point (10) and from the pole N, are here stated. For the graphical construction see Fig. 10, and for the explanation of this construction see page 701.

DATA FOR PARTIAL SUMMATIONS.

Summation	a	b	x_n	x_m	Formula
a	9.8	7.4	4.06	8.20	(5)
b	15.5	0	12.95	30.08	(4)
*c	0	0	18.00	34.18	(1)
d	0	0	34.18	51.26	(3)

$$y_a = \log_e \frac{8.2 + \sqrt{\overline{9.8}^2 + \overline{8.2}^2}}{4.06 + \sqrt{\overline{9.8}^2 + \overline{4.06}^2}} -$$

$$\frac{14.8}{\sqrt{\overline{9.8}^2 - \overline{7.4}^2}} \left(\tan^{-1} \frac{8.2 + \sqrt{\overline{9.8}^2 + \overline{8.2}^2} + 7.4}{\sqrt{\overline{9.8}^2 - \overline{7.4}^2}} \right.$$

$$\left. \tan^{-1} \frac{4.06 + \sqrt{\overline{9.8}^2 + \overline{4.06}^2} + 7.4}{\sqrt{\overline{9.8}^2 - \overline{7.4}^2}} \right)$$

$$= \log_e \frac{20.92}{14.66} - \frac{14.8}{6.4} \left(\tan^{-1} \frac{28.32}{6.4} - \tan^{-1} \frac{22.06}{6.4} \right)$$

$$= 2.304 \log_{10} 1.43 - 2.31 \left(\tan^{-1} 4.42 - \tan^{-1} 3.45 \right)$$

$$= 2.304 \times 0.155 - 2.31 \times \frac{\pi}{180^\circ} (77.25^\circ - 73.83^\circ)$$

$$= .357 - .137 = .22$$

$$y_b = \frac{30}{17.1}\log_e \frac{30 + \sqrt{\overline{15.5}^2 + \overline{30}^2}}{12.95 + \sqrt{\overline{15.5}^2 + \overline{12.95}^2}}$$

$$- \frac{\sqrt{\overline{15.5}^2 + \overline{30}^2} - \sqrt{\overline{15.5}^2 + \overline{12.95}^2}}{17.1}$$

$$= 2.304 \times 1.75 \log_{10} 1.92 - .795 = .35$$

$$y_c = \log_e \frac{34.1}{18} = 2.304 \log_{10} 1.89 = .636$$

$$y_d = \frac{51.26}{17.13}\log_e \frac{51.26}{34.13} - 1 = 2.304 \times 3 \log_{10} 1.50 - 1 = .21$$

and therefore

$y_{10} = .22 + .35 + .636 + .21 = 1.416$, which is the value of the *proportional* flux density ordinate at point (10).

Discussion.

Mr. Edward P. Thompson:—This paper brings up certain points in reference to magnetic flux and touches upon cases where the armature is smooth, and where the armature is provided with slots, and will serve to explain some experiments which I happen to be acquainted with that were carried on for the purpose of improving dynamos used in telephony to prevent the whistling or the buzzing sound so often heard when dynamos are so employed, and different experimenters have worked toward getting a dynamo that would give practically as steady a current as a battery.

I would like to draw a sketch on the board to illustrate this. These experiments possess interest because the combination by which the desired kind of current is obtained is novel. It has been through the mill of the Patent Office, and attempts have been made to try to prove that is old.

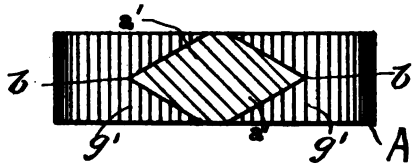


Fig. 21.

Say *a'* is a projection of a pole, shown in section upon the armature A, in Fig. 21. When this armature has slots, although the poles *b* are pointed, yet there is no steady magnetic flux whatever produced as proved by trial. The current that is generated will show its unsteady constitution by producing a buzz in the telephone. But by letting the armature have a smooth surface, and the smoother the better, and then having the conductors go across in that style as shown at *g'*, the current that is generated is equivalent to a battery current. Of course, before the telephone came into use, currents were supposed to be perfectly steady anyway; but the telephone shows whether a current is steady or not, and by having a combination like that, the current cannot be distinguished from the battery current.

This simple form of "telephone" dynamo was invented by Arthur E. Jenney. Patent granted on appeal January 29. I have alluded to it because I thought it might be of interest to couple up a useful application with mathematical demonstrations.

Mr. E. M. Archibald:—I observe that on page 720 of the paper, Prof. Goldsborough has referred to some experiments carried on by Mr. Herdt and myself last spring. The ratio between the flux in the slot and the flux in the armature as calculated by him was 37 per cent., while the percentage obtained by experiment was only 25. In our experiments we found, using practically the same method, that for a revolving field distributed winding machine, that this ratio was very nearly what his calculated result was, the value being 34.6 per cent. The result that we obtained was when the field was stationary, and when it is revolving the distribution is distorted slightly in the direction of rotation; but the value we were not able to exactly determine when it was revolving, because some of our apparatus broke down. But from other curves that we obtained in checking up the above, we found that the value when stationary can be taken as very nearly the same, as when the machine is running.

COMMUNICATED BY HARRIS J. RYAN, AUGUST 18, 1899, AFTER THE ADJOURMENT OF THE BOSTON MEETING.

[This is in discussion of Prof. Goldsborough's paper, vol. xvi., p. 461, and was omitted through oversight from its proper location.]

At the World's Fair a committee of the Board of Awards in the Department of Electricity made a series of efficiency tests of the large engine dynamos there exhibited. The efficiency load curves of the generators as determined by the indicator cards and those calculated from no-load core losses, electrical data, and output observations did not agree at the higher load values. They differed in all cases from three to five per cent. A satisfactory check on the efficiency measurements at the time could not be made because of these discrepancies, which were finally traced to the variation of the core losses with the generator loads. At the time and under the circumstances no satisfactory method could be found to determine independently the core loss variations with the generator loads. The results of these tests were not published for another reason—the consent to publication could not be obtained from all the makers concerned. I have recalled this experience for the purpose of emphasizing the importance of Prof. Goldsborough's paper.

OBITUARY.

Joseph Clement, who was elected an associate member of the **Institute** April 26th, 1899, was killed in the battle of Zand River, a few miles north of Bloemfontein, in June, 1900. Mr. Clement was born in Oakland, California, and was 28 years of age at the time of his death. He was educated in California, and went from there in 1894 to South Africa, where he joined the electrical staff of the De Beer's Consolidated Mines, Ltd., in Kimberley. Leaving there shortly afterward he became connected with Messrs. Reunert & Lenz, Electrical Engineers in Johannesburg, and shortly afterward was appointed Electrician to the Rand Mines, Ltd., and the Crown Reef Gold Mining Co., Ltd., both of Johannesburg. In the latter capacity he had much important work under his immediate control, and carried out electrical undertakings of considerable magnitude for the two companies mentioned. Upon the outbreak of war between England and the South African Republic Mr. Clement volunteered, and was appointed Lieutenant in the Railway Pioneer Regiment, a volunteer corps organized by the late L. I. Seymour, an American of great prominence and distinction in Johannesburg. Mr. Clement and his commanding officer, Major Seymour, both met their death at one of the engagements which occurred along the line of communications after Lord Roberts' march to Pretoria. Both fell fighting in the front rank of their command. Mr. Clement had been married only a short time before to Miss Josephine Webber, daughter of Mr. George E. Webber, General Manager of the Rand Mines, Ltd., who, with his infant daughter, survives him.

Associate Members elected at a meeting of the Executive Committee, held Thursday, July 12th, 1900.

ADLER, ALPHONSE A.	Electrician, New York Post Graduate Hospital, 20th Street and 2d ave., residence, 287 Eldridge St., N. Y.	F. E. Kinsman. W. A. Anthony. Ralph W. Pope.
AMBLER, WILLIAM.	Student at Cornell University, residence, 76 Lincoln Ave., Cleveland, Ohio.	Harris J. Ryan. Fred'k. Bedell. Edw. L. Nichols.
BARTON, PHILIP PRICE.	Assistant Superintendent, The Niagara Falls Power Co., Niagara Falls, N. Y.	L. B. Stillwell. Chas. F. Scott. A. J. Wurts.
BLISS, LOUIS DENTON.	Principal Bliss Electrical School, 614 12th Street, Washington, D. C.	G. K Woodworth. C. W. Swoope. H. P. Hill.
FLEMING, JOHN F.	Electrical Contractor, Brookline, Mass.	Chas. R. Cross. Chas. H Herrick. Chas. B. Burleigh.
GARTLEY, ALONZO.	General Manager, Hawaiian Electric Co., Honolulu, H. I.	C. L. Cory. A. M. Hunt. W. F. C. Hasson.
TINGLEY, E. M	Westinghouse Elec. & Mfg. Co., residence, Amber Club, Pittsburg, Pa.	Chas. F. Scott. A. J. Wurts. L. B. Stillwell.
WESTON, SYDNEY F.	Assistant Engineer, Waldorf-Astoria Hotel, residence, 22 Gramercy Park, N. Y. City.	H. A. Storrs. Geo. F. Stever. Tom H. Gregg.
WOODSWORTH, PHILIP BELL.	Professor in charge of Electrical Engineering, Lewis Institute, Chicago, residence, 123 South Park Ave., Austin, Ill.	Albert Scheible. Geo. P. Nichols. E. A. Schweitzer.
ZANI, ARNALDO P.	Electrical Engineer, Thomson-Houston Co., Piazza Cartello 5 Milano, Italy.	C. P. Steinmetz. J. W. Lieb Jr. Philip Torchio.

Total 10.

Associate Members elected at a meeting of the Executive Committee, New York, Thursday, July 26th, 1900.

ACKLAND, E. W.	Electrical Engineer, Perth Electric Tramways, Perth, Western Australia.	S. W. Childs. J. S. Fitzmaurice. W. G. T. Goodman
ALLEN, ALBERT P.	General Inspector, American Tel. & Tel. Co., 15 Dey St., residence, 44 Irving Place, New York City.	John J. Carty. F. A. Pickernell. A. N. Mansfield.
AUEL, CARL B.	Engineer, British Westinghouse Elec. & M'f'g. Co., Amber Club, East End, Pittsburgh, Pa.	Chas. F. Scott. P. A. Lange. C. E. Skinner.

Baker, Arthur O.	Superintendent, Wichita Gas, Electric Light and Power Co., Box 574 Wichita, Kansas.	F. E. Kinsman. Ralph W. Pope. H. D. McVay.
Berg, Geo. H.	New England Sales Agent, Bullock Electric Mfg. Co., 70 Kilby St., Boston, Mass , residence, Medford, Mass.	Robert T. Lozier. John L. Hall. C. V. Edwards.
Carnaghan, E. D.	In charge of machinery with Cipriano Guerrero, Durango, Do. Mexico.	C. F. Beames. R. H. Evans. M. T. Thompson.
Dysterud, Emil	Superintendent and General Manager, Electric Light & Power Co., Monterey, Nuevo Leon, Mexico.	P. H. Evans. C. F. Beames. S. A. Dyer.
Elgin, James Meikle	Chief of Electric Dept. Edison Electric Light Co., of Philadelphia, 10th and Sansom Sts., residence, 4230 Chester Ave., Philadelphia, Pa.	C. Toerring. Minford Levis. Wm. C. L. Eglin.
Farrand, Dudley	General Manager, United Electric Company of New Jersey, 207 Market St., residence, 141 Clinton Ave., Newark, N. J.	Wm. Stanley. John F. Kelly. C. C. Chesney.
Harter, Bret	Superintendent D. R. R. & L. O. Railway, Rochester, Mich.	C. G. Young. W. C. Burton. Harvey E. Molé.
Hitzeroth, L. D.	Superintendent, Electrical Department General Electric Co., 229 Stevenson St., residence, 452 Bryant St., San Francisco, Cala.	F. V. T. Lee. C. O. Poole. F. F. Barbour.
Howland, Lewis A.	Electrical Engineer Royal Electric Co., Montreal, Que.	P. G. Gossler. Robert A. Ross. R. B. Owens.
Imlay, L. E.	Construction Engineer, Westinghouse Elec. & Mfg. Co., Niagara Falls, N. Y.	P. M. Lincoln. Chas F. Scott. W. K. Dunlap
Kent, James Martin	Instructor in Steam and Electricity, Manual Training High School, Kansas City, Mo.	Jas. Lyman. L. Stieringer. E. R. Weeks.
Kennedy, Jeremiah J.	Mechanical Engineer with J. G. White & Co., 29 Broadway, New York.	H. A. Lardner. Wm. C. Burton. Geo.W.Frank,Jr.
McLimont, A. W.	With State Electrical Engineer, Gobirino de Guanajuato. Box 25, Guanajuato, Mexico.	C. F. Beames. P. H. Evans. S. A. Dyer.
Nicholson, Samuel L.	With Westinghouse Elec. & Mfg. Co , 120 Broadway, New York residence, 820 President St , Brooklyn, N. Y.	R. D. Mershon. Wm.K.Archbold. C. O. Mailloux.
Parke, Roderick J.	Consulting Electrical Engineer, 409 Temple Building, Toronto, Canada.	S. S. Wheeler. Chas. F. Scott. Norman Ross.

Smith, Wm. Stuart	Consulting Engineer, Electrical and Mechanical. 2538 Dwight Way, Berkeley, Cala.	F. A. C. Perrine. J. A. Lighthipe. W. D. Weaver.
Smith, Walter F.	General Manager, United Gas Improvement Co., Philadelphia, Pa., residence, 2010 Ontario St., Philadelphia, Pa.	Herbert Lloyd. Chas. Blizard. R. H. Klauder.
Smith, Frederick B.	With Smith & Crockett Electrical Specialties, 70 Summer St., Boston, Mass.	F. Wm. Erickson. Chas. H. Herrick. R. W. Pope.
Spiese, F. P.	Secretary, Treasurer and Manager the Edison Electric Illuminating Co., Tamaqua, Penn.	W. S. Andrews. C. L. Edgar. W. S. Howell:
Tidd, Geo. N.	Electrical Engineer and Manager, Beacon Light Co., Chester, Pa.	Herbert Lloyd. Chas. Blizard. R. H. Klauder.
Varney, Frank H.	Station Foreman San Francisco Gas and Electric Co., 2912 Mission Street, San Francisco, Cala.	F. F. Barbour. J. A. Lighthipe. F. E. Smith.
Wall, Louis James Benard	Full Partner, Splatt, Wall & Co., Perth, Western Australia.	W. D. Weaver. J. E. Woodbridge Cecil P. Poole.

Total 25.

Associate Members Transferred to Full Membership.

Approved by Board of Examiners, June 8th, 1900.

E. J. Bechtel,	Superintendent Construction, Toledo Traction Company, Toledo, Ohio.

DIED.

Rittenhouse:—At Denver, Colo., February 26th, 1900, Charles T. Rittenhouse, eldest son of M. and R. L. Rittenhouse of New York City. Mr. Rittenhouse was a graduate of Columbia, and formerly on the editorial staff of the *Electrical World*. He was elected an Associate Member of the INSTITUTE, February 21st, 1894.

Weise.—At Princeton, Ill., May 19th, 1900, of heart failure, Will Morrison Templeton Weise, Manager of the firm of Weise Brothers, electrical contractors, Davenport, Ia. Mr. Weise was born in Princeton, January 18th, 1865, where he was educated in the public schools, and subsequently engaged in electrical work in Seattle and Chicago. In 1897 he entered into partnership with his brother at Davenport. He was elected an Associate Member of the INSTITUTE August 18th, 1897.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

CATALOGUE OF MEMBERS.

MAY 15TH, 1901.

HONORARY MEMBERS.

Name.	Address.	Date of Membership.
KELVIN, *Lord*, *D.C.L.*, *LL.D.*, *F.R.S.*	15 Eaton Place, London, S. W., England,	H.M. May 17, 1892
PREECE, *Sir*. **WILLIAM**. H., *K.C.B.*, *F.R.S.*	Consulting Electrical Engineer, 13 Queen Anne's Gate, London, S. W., Eng.; residence, Gothic Lodge, Wimbledon.	H.M. Oct. 21, 1884

Honorary Members, 2.

MEMBERS.

Name.	Address.	Date of Membership.
ABBOTT, ARTHUR V.	(*Vice-President*) Chief Engineer, Chicago Telephone Co., 203 Washington St., Chicago, Ill.	A Oct. 21, 1890 M Jan. 16, 1895
ACHESON, EDW. G.	President, The Carborundum Co., Niagara Falls, N. Y.	A Jan. 3, 1888 M May 1, 1888
ADAMS, ALTON D.	Consulting Engineer, Box 1377, Boston, Mass.	A April 18, 1893 M Jan. 17, 1894
AHEARN, THOMAS	Ahearn & Soper, Electrical Supplies, Ottawa, Ont.	A July 12, 1887 M Sept. 6, 1887
ALBANESE, G. SACCO	Electrical Engineer, Tramways Electriques de Nice, Nice, France.	A Sept. 20, 1893 M Sept. 27, 1899
ALBRIGHT, H. FLEETWOOD	Electrical Engineer, Western Electric Co., New York; residence, 60 Sayre St., Elizabeth, N. J.	A Sept. 27, 1892 M June 20, 1894
ALDRICH, WILLIAM S.	Professor of Electrical Engineering, University of Illinois, Champaign, Ill.	A Mar. 15 1892 M April 25, 1900
ANDREWS, WM. S	Manager Central Station Sales, General Electric Co., residence, 242 Union St, Schenectady, N. Y.	A Mar. 5, 1889 M April 22, 1896
ANSON, FRANKLIN ROBERT	President, Salem Light, Heat and Power Co., Salem, Ore.	A Feb. 27, 1895 M Nov. 23, 1898

Name.	Address	Date of Membership.
ANTHONY, PROF. W. A.	(*Past President.*) Consulting Electrician, Cooper Union; residence, 313 W. 33d St., New York, N. Y.	A Dec. 9, 1884 M Jan. 6, 1885
ARMSTRONG, CHAS. G.	Consulting Electrical Engineer, Fisher Building, Chicago, Ill.	A Sept. 27, 1892 M Aug. 31, 1898
ARNOLD, BION J.	Consulting Electrical Engineer, 1541 Marquette Bldg. and 4128 Prairie Ave., Chicago, Ill.	A Oct. 25, 1892 M Nov. 15, 1893
AYER, JAMES I.	General Manager American Electric Heating Corporation, Franklin and Sidney Sts., Cambridge, Mass.	A May 19, 1891 M April 19, 1892
AYRES, BROWN	Professor of Physics and Electrical Engineering, Tulane University, New Orleans, La.	A Dec. 16, 1891 M Mar. 15, 1892
BADT, LIEUT. FRANCIS B.	President, Badt-Goltz Engineering Co., 1504 Monadnock Block and 6506 Lafayette Ave., Chicago, Ill.	A April 19, 1892 M Mar 25, 1896
BAILLARD, E. V.	Manufacturer of Electrical Instruments and Fine Machinery, Fox Building, New York City.	A Dec. 3, 1889 M Jan. 16, 1895
BALDWIN, BERT L.	Mechanical Engineer, The Cincinnati Street R'way Co., 73 Perin Bldg., Cincinnati, O.	A April 22, 1896 M Nov. 18, 1896
BARBOUR, FRED FISKE	Manager, Sales Department, Pacific District, General Electric Co., Claus Spreckels Bldg., San Francisco, Cal., and 1383 Franklin St., Oakland, Cal.	A May 16, 1893 M Sep. 26, 1900
BARSTOW, WILLIAM S.	(*Manager.*) General Manager, Edison Electric Illuminating Co., 360 Pearl St., Brooklyn, N. Y.	A Feb. 21, 1894 M April 26, 1899
BATCHELOR, CHAS.	Electrical Engineer, Exchange Court Bldg., 52 Broadway; residence, 33 W. 25th St.	A June 8, 1887 M July 12, 1887
BATES, JAMES H. *M. E.*	Engineering Department Edison Illuminating Co., 57 Duane St., N.Y. City, Box 118 Hoboken, N.J.	A Sept. 6, 1887 M Oct. 1, 1889
BAYLIS, ROBERT NELSON	The Baylis Co., 99 Cedar St., New York City.	A Oct. 1, 1889 M May 17, 1892
BEAMES, CLARE F.	Chief Engineer, Compania Mexicana de Gaz y Luz Electrica, 7 1ª San Francisco, City of Mexico.	A May 21, 1895 M Feb. 28, 1901
BECHTEL, ERNEST J.	Superintendent Lighting and Construction, Toledo Traction Co., Toledo, O.	A Mar. 24, 1897 M July 27, 1900
BEDELL, DR. FREDERICK,	Assistant Professor in Physics, Cornell University, Ithaca, N. Y.	A April 21, 1891 M May 19, 1896
BELL, PROF. A. GRAHAM	(*Past President.*) 1331 Conn. Ave., Washington, D. C., and Baddeck, N. S.	A April 15, 1884 M Oct. 21, 1884
BELL, DR. LOUIS	Electrical Engineer, Boston, Mass.	A May 20, 1890 M June 18, 1890

Name.	Address.	Date of Membership.
Bernard, Edgar G.	Manufacturer, 450 Fulton St., Troy, N. Y.	A. Jan. 5, 1886 M July 12, 1887
Betts, Philander 3d	Mech. & Electrical Engineer, Bureau of Yards and Docks, Navy Dept., residence, 653 I St., S. E., Washington, D. C.	A Mar. 25, 1896 M Jan. 25, 1899
Billberg, C. O. C.	Electrical Engineer, 17 Hill Street, Newark, N. J.	A Mar. 21, 1894 M Feb. 27, 1895
Birdsall, E. T. *M. E.*	Consulting Electrical Engineer, 26 Cortlandt St., residence, 56 West 38th St., New York City.	A June 8, 1887 M Nov. 1, 1887
Blades, Harry H.	Electrical Engineer, 419 Cass Ave., Detroit, Mich.	A April 19, 1892 M May 21, 1895
Blake, Francis	Auburndale, Mass.	A Sept. 3, 1889 M Oct. 1, 1889
Blodgett, Geo. W.	Electrical Engineer, B. & A. R. R. and Consulting Electrician, Boston, residence, Auburndale, Mass.	A July 12, 1887 M Sept. 6, 1887
Blood, John Balch	Blood and Hale, Consulting Engineers, Room 22–A, Equitable Building, Boston, Mass.	A June 20, 1894 M Dec. 18, 1895
Boggs, Lemuel Stearns	With Sargent & Lundy, 1000 Isabella Bldg., Chicago, Ill.	A Sept. 20, 1893 M May 17, 1898
Boileau, Willard E.	General Superintendent Lighting and Power Dept. and Electrical Engineer, Columbus R. R. Co., Columbus, Ga.	A Sept. 19, 1894 M Mar. 25, 1896
Bosch, Adam	Sup't Fire Alarm Telegraph, Newark, N. J.	A April 15, 1884 M Jan. 6, 1885
Bottomley, Harry	Bellows Falls Electric Light Co., Bellows Falls, Vt.	A April 2, 1889 M Jan. 22, 1896
Bourne, Frank	Electrical Engineer, 26 Cortlandt St., New York City.	A April 21, 1891 M Nov. 15, 1892
Boyer, Elmer E.	Foreman, Testing Department, Lynn Works, General Electric Co., Lynn, Mass.	A Sept. 25, 1895 M Mar. 25, 1896
Boynton, Edward C.	Electrical Dep't, N. Y., N. H. & H. R. R., New Haven, Ct.	A Aug. 6, 1889 M Nov. 24, 1891
Bradley, Chas. S.	(*Manager.*) President, Ampere Electro Chemical Co, 44 Broad Street, residence, 42 W. 84th St., New York City.	A May 24, 1887 M Dec. 6, 1887
Brady, Frank W., *M. E.*	Professor of Engineering New Mexico College of Agriculture and Mechanic Arts, Mesilla Park, N. M.	A June 20, 1894 M Mar. 28, 1900
Brenner, William H.	Constructing Engineer, Care of Frazar & Co., Yokohama, Japan.	A Sept 20, 1893 M Mar. 21, 1894

Name.	Address.	Date of Membership.
Brinckerhoff, Henry Morton	General Manager, Metropolitan West Side Elevated R. R.; 1001 Royal Insurance Bldg., Chicago, Ill.	A Sept. 23, 1896 M Dec. 16, 1896
Brooks, Morgan	Professor of Electrical Engineering, University of Nebraska; residence, 512 So. 16th St., Lincoln, Neb.	A May 20, 1890 M June 17, 1890
Brown, Alfred S.	Electrical Engineer, Western Union Telegraph Co., 195 Broadway, P. O. Box 856, New York City.	A Mar. 18, 1890 M Feb. 21, 1893
Brown, J. Stanford, ***E.E.,*** [Life Member.]	Consulting Electrical Engineer, Cor. Sec'y, Carpenter Steel Co., 1 Broadway; Vice-Pres't and Treas. Mutual Realty and Loan Corp; Treas., of the Realty-Loan Trust Co., 203 Broadway, New York City; residence, Park Hill, Yonkers, N.Y.	A Sept. 6, 1887 M Nov. 1, 1887
Browne, Sidney Hand.	Consulting Engineer, Duncan and Browne, Md. Tel. Bldg., residence, The St. Paul Apartments, Baltimore; P & A. Tel. Bldg., Pittsburg, Pa.	A Apr. 28, 1897 M Nov. 23, 1898
Brush, Chas. F.	Electrical Engineer, 453 The Arcade, Cleveland, O.	A April 15, 1884 M Oct. 21, 1884
Buck, Harold W.	Electrical Engineer, Niagara Falls Power Co., 170 Buffalo Ave., Niagara Falls, N. Y.	A Jan. 16, 1895 M Apr. 26, 1901
Burch, Edward P.	Consulting Electrical Engineer, 1210 Guaranty Building, Minneapolis, Minn.	A Jan. 28, 1898 M May 17. 1898
Burgess, Chas. Fred'k.	Ass't Professor of Electrical Engineering, University of Wisconsin, residence, 609 Lake St., Madison, Wis.	A Mar. 25, 1896 M Apr. 26, 1901
Burleigh, Chas. B.	Electrical Engineer, General Electric Co., 200 Summer St., Boston, residence, 1 Oak Terrace, Malden, Mass.	A April 21, 1891 M Feb. 16, 1892
Burton, William C.	Electrical Engineer, J. G. White Co., 22a College Hill, London, E. C., Eng.	A Sept. 20, 1893 M Dec. 27, 1899
Cahoon, Jas. Blake	Consulting Engineer, Onondaga County Savings Bank Building; residence, 729 Crouse Ave., Syracuse, and 40 Wall St., New York.	A June 17, 1890 M May 19, 1891
Carichoff, E. R.	Electrical Engineer, Sprague Electric Co., 52 Broadway, New York, N. Y.	A Mar. 21, 1894 M May 15, 1900
Carhart, Henry S.	Prof. of Physics, University of Michigan, Ann Arbor, Mich.	A Sept. 25, 1895 M April 22, 1896
Carroll, Leigh	President Algiers Waterworks and Electric Co., 708 Union St., New Orleans, La.	A Oct. 1, 1889 M Nov. 12, 1889

Name.	Address.	Date of Membership.
Carus-Wilson, Prof. Charles A.	Consulting Engineer, 41 Old Queen St., Westminster, London, Eng.	A April 18, 1894 M April 17, 1895
Chamberlain, J. C.	Vice President and Manager, The Electric Launch Co., Bayonne City, N.J.; residence, 1 West 81st St., New York City.	A Dec. 6, 1887 M Jan. 3, 1888
Chandler, Charles F.	Professor of Chemistry, Columbia University, New York City.	A Jan. 20, 1891 M June 7, 1892
Cheney, W. C.	Electrical Engineer and Contractor, Portland, Or.; residence, Oregon City, Or.	A Sept. 22, 1891 M Nov. 21, 1894
Chesney, Cummings C.	Chief Electrical Engineer, Stanley Electric M'f'g. Co., Pittsfield, Mass.	A June 20, 1894 M Nov. 22, 1899
Childs, Arthur Edwards, *B. Sc. M.E., E.E.*	Vice-President and Treasurer, The Light, Heat and Power Corporation, 23 Central St., Boston, Mass.	A June 20, 1894 M April 17, 1895
Chubbuck, H. Eugene	General Manager, Quincy Lighting Companies, and Manager Quincy Railway and Carrying Co., Quincy, Ill.	A Dec. 4, 1888 M April 26, 1899
Churchill, Arthur	British Thomson-Houston Co., 83 Cannon Street, London, E. C., Eng.	A April 15, 1890 M Jan. 17, 1893
Clark, Ernest P.	Electrical Engineer, B. Altman & Co, 19th St. and 6th Ave.; residence, 229 W. 18th St., New York City.	A Jan. 8, 1887 M Nov. 1, 1887
Clarke, Chas. L.	Electrical Engineer and Patent Expert, 31 Nassau St., New York City.	A April 15, 1884 M Jan. 6, 1885
Colby, Edward A.	Consulting Engineer, Lock Box 113, Newark, N. J.	A April 2, 1889 M May 7, 1889
Colvin, Frank R.	Box 217, Roselle, N. J.	A April 18, 1894 M May 21, 1895
Comstock, Louis K.	Electrical Engineer, George A. Fuller Co., 137 Broadway, New York.	A Dec. 20, 1893 M Nov. 20, 1895
Condict, G. Herbert	Electrical Engineer, Columbia and Electric Vehicle Co., Hartford, Ct.	A July 12, 1887 M Sept. 6, 1887
Cornell, Charles L.	Treasurer, Niles-Bement-Pond Co., 136 Liberty St., New York City.	A Feb. 7, 1890 M June 27, 1895
Coster, Maurice	45 Rue de la, Arcade, Paris, France.	A Sept. 25, 1895 M Mar. 25, 1896
Cowles, Alfred H.	President the Cowles Electric Smelting and Aluminum Co., 361 The Arcade; residence, 656 Prospect St., Cleveland, O.	A Mar. 5, 1886 M May 7, 1889
Crocker, Francis Bacon [Life Member.]	(*Past-President*) Professor of Electrical Engineering, Columbia University; residence, 14 W. 45th Tel. 3823 38th New York.	A May 24, 1887 M April 2, 1889

Name.	Address.	Date of Membership.
Cross, Charles R.	Thayer Professor of Physics, and Director of the Rogers Laboratory, Mass. Institute of Technology, Boston, Mass.	A April 15, 1884 M Oct. 21, 1884
Cushing, Harry Cooke, Jr.	Electrical Consulting and Constructing Engineer, 39 Cortlandt St., New York City.	A Sept. 19, 1894 M Nov. 18, 1896
Cuttriss, Chas.	Electrician, The Commercial Cable Co., 20 Broad St., New York.	A Nov. 1, 1887 M Dec. 6, 1887
Daft, Leo	Consulting Electrical Engineer, 50 Hartfield Road, Wimbledon, London S. W. Eng.	A Dec. 9, 1884 M Jan. 6, 1885
Darlington, Frederic W.	Consulting Electrical and Mechanical Engineer, 1120 Real Estate Trust Bldg, Philadelphia, Pa.	A Sept. 19, 1894 M Nov. 25, 1895
Davidson, A.	Cable Engineer and Electrician, Central and South American Telegraph Co., Lima, Peru.	A May 18, 1897 M Oct. 27, 1897
Davis, Albert G.	Manager, Patent Dep't. General Electric Co., Schenectady, N.Y.	A Mar. 23, 1898 M Sept. 26, 1900
Davis, Charles H., *C. E.*	Consulting Engineer, Broad Exchange Bldg. New York City, 204 Walnut Place, Philadelphia, Pa., 4 State Street, Boston, Mass.	A Mar. 18, 1890 M June 17, 1890
Davis, Minor M.	Traffic Manager, Postal Telegraph-Cable Co., 253 Broadway, New York City.	A April 6, 1886 M May 16, 1893
Dawson, Philip	Associate and Chief Engineer with R. W. Blackwell, 39 Victoria St., Westminster, London, Eng.	A Sept. 25, 1895 M Feb. 17, 1897
Decker, Edward P.	Engineer, with Westinghouse, Church, Kerr & Co., 26 Cortlandt St., New York City; residence, 496 Second St., Brooklyn, N. Y.	A Feb. 26, 1896 M Oct. 27, 1897
deKhotinsky, Capt. Achilles	Late Chief Electrician and Torpedo Officer, Imperial Russian Navy, 5526 Jefferson Avenue, Chicago, Ill.	A Oct. 27, 1891 M Nov. 22, 1899
Delany, Patrick Bernard	Inventor, South Orange N. J.	A April 19, 1884 M Nov. 24, 1891
Denham, John	Electrician, Cape Government, Cape Town, South Africa.	A Jan. 24, 1900 M May 15, 1900
Dickenson, Samuel S.	Sup't, Commercial Cable Co., Hazel-Hill, Guysborough Co., N. S.	A Mar. 6, 1888 M Oct. 1, 1889
Diehl, Philip	Inventor, Singer Sewing Machine Co., 508 Morris Ave., Elizabeth, N. J.	A April 15, 1884 M Dec. 9, 1884
Dion, Alfred A.	General Supt., The Ottawa Electric Co., Sparks St., Ottawa, Ont.	A Jan. 7, 1890 M Nov. 15, 1893
Doane, Samuel Everett [Life Member.]	Sup't. Marlborough Electric Machine and Lamp Co., Marlborough, Mass.	A Aug. 6, 1889 M June 27, 1895

Name.	Address.	Date of Membership.
Dodge, Omenzo G., Prof.	U. S. Navy, Naval Academy, Annapolis, Md.	A Sept. 20, 1893 M April 17, 1895
Doyer, H.	Consulting Electrical Engineer, 8 Phoenixstraat Delft, Holland.	A Jan. 7, 1890 M Mar. 18, 1890
Dommerque, Franz J.	Chief Engineer, Kellogg Switchboard and Supply Co., cor. Congress and Green Sts., Chicago, Ill.	A Oct. 17, 1894 M Mar. 25, 1896
Donner, William H.	Ingleside, 31 Lyndhurst Road Hampstead, Eng.	A Nov. 18, 1890 M Dec. 16, 1890
Dow, Alex	Manager, Edison Illuminating Co., 18 Washington Ave.; residence, 844 Cass Ave., Detroit, Mich.	A Sept. 20, 1893 M Dec. 18, 1895
Dudley, Charles B	Chemist and Scientific Expert, Penn. R. R. Co., Drawer 334. 1219 Twelfth Ave., Altoona, Pa.	A Oct. 1, 1889 M Nov. 12, 1889
Dunbar, F. W.	S. W. Cor. Greene and Congress Sts., Chicago; residence, Highland Park, Ill.	A Dec. 21, 1892 M May 16, 1893
Duncan, Dr. Louis	(*Past-President*) Duncan & Browne, Consulting Engineers, Baltimore, Pittsburg. Philadelphia and 71 Broadway, New York.	A July 12. 1887 M Sept. 6, 1887
Dunlap, Will Knox	Supt. of Construction, Westinghouse Elec. and Mfg. Co., Pittsburg, Pa.	A Sept. 25, 1889 M June 24, 1895
Dunn, Gano Sillick, *M.S.,E.E.*	(*Vice-President*). Chief Engineer, Crocker-Wheeler Co., Ampere, N.J.; residence, 115 W. 71st St., New York City.	A April 21, 1891 M June 20, 1894
Dunston, Robt. Edward	Superintendent, State Line and Sullivan R. R., Towanda, Pa.	A Oct. 27, 1891 M Feb. 16, 1892
Dyer, R. N.	Patent Attorney, 31 Nassau St., New York City.	A July 12, 1887 M Sept. 6, 1887
Edison, Thomas A.	Mechanician and Inventor, Llewellyn Park, N. J.	A April 15, 1884 M Oct. 21, 1884
Edgar, C. L.	President Edison Elec. Illuminating Co. of Boston, 3 Head Place, Boston; residence, 259 Kent St., Brookline, Mass.	A Jan. 22, 1896 M May 19, 1896
Egger, Ernst	Technical Director, Vereinigte Elektricitäts Actien Gesellschaft, Simmeringstr, 187, Vienna, X., Austria.	A Feb 21, 1893 M Mar. 21, 1894
Emmet, W. L. R.	(*Vice-President.*) Electrical Engineer, General Electric Co., Schenectady, N. Y.	A June 6, 1893 M Jan. 17, 1894
Fessenden, Reginald A.	Special Agent, U. S. Weather Bureau, Washington, D. C.	A Oct. 21, 1890 M Dec. 16, 1890
Field, Cornelius J., *M. E.*	Consulting and Constructing Engineer, Church, Lane and 37th St., Brooklyn, N. Y.	A June 8, 1887 M Nov. 1, 1887
Field, Henry George	Consulting Engineer, Field & Hinchman, 1203 Majestic Building, Detroit, Mich.	A April 22, 1896 M Dec. 16, 1896

Name.	Address.	Date of Membership.
Field, Stephen D.	Electrical Engineer, Compagnie Genevoise de Tramways Electriques. A La Jonction, Geneva, Switzerland.	A April 15, 1884 M Oct. 21, 1884
Fischer, Gustave J.	Engineer for Tramway Construction, Public Works Department, Sydney, N. S. W.	A Jan. 20, 1891 M May 17, 1898
Fish, Walter Clark	Manager Lynn Works, General Electric Co., Lynn, Mass.	A June 26, 1891 M Feb. 26, 1896
Fisher, Henry W.	Electrician and Director of Elec. and Chem. Laboratories; The Standard Underground Cable Co., Pittsburg, Pa.	A Jan. 16, 1895 M April 26, 1901
Fitzmaurice, James S.	Chief Engineer, The Electric Light Branch, 210 George St., Sydney, N. S. W.	A Sept. 20, 1893 M Mar. 21, 1894
Flack, J. Day, *M. E.*	Supt. Engineer of the International Smokeless Powder and Dynamite Co., South Amboy, N. J.; residence, 80 Carlton St., East Orange, N. J.	A Dec. 6, 1887 M May 21, 1895
Fortenbaugh, S. B.	112 Cannon Street, London E. C. Eng.	A April 17, 1895 M Dec. 16, 1896
Foster, Horatio A.	Electrical Engineer, 650 Bullitt Building, Philadelphia, Pa.	A June 8, 1887 M Sept. 6, 1887
Foster, Samuel L.	Chief Electrician, Market Street Railway Co., Market & Valencia Sts.; residence, 3687 24th St., San Francisco, Cal.	A Feb. 26, 1896 M Nov, 18, 1896
Freedman, William H.	Professor of Electrical Engineering University of Vermont; residence, 222 So. Union St., Burlington, Vt.	A Mar. 18, 1890 M Dec. 18, 1895
Freeman, Dr. Frank L.	Attorney-at-Law, Solicitor of Patents, Electrical Expert, 931 F St., Washington, D. C.	A May 7, 1889 M Sept. 3, 1889
Gale, Horace B.	Mechanical and Electrical Engineer, Natick, Mass.	A Nov. 15, 1892 M May 16, 1893
Garratt, Allan V.	Chief Engineer, Lombard Waterwheel Governor Co., 61 Hampshire St., Boston; residence, 6 Newbern St., Jamaica Plain, Mass.	A April 2, 1889 M May 7, 1889
Gerry M. H., Jr.,	Engineer and Supt., Helena Water and Electric Power Company, Helena, Mont.	A April 18, 1893 M Oct. 21, 1896
Geyer, Dr. Wm. E.	Stevens Institute of Technology, Hoboken, N. J.	A June 5, 1888 M Sept. 7, 1888
Gharky, William David	Electrical Engineer, Firm of Clement & Gharky, 2347 Park Ave., Philadelphia, and 56 McGill Bldg. Washington, D. C.	A May 21, 1895 M Feb. 26, 1896
Gifford, Clarence E.	Professor of Engineering, Caton's College; residence, 878 Prospect Ave., Buffalo, N. Y.	A May 16, 1893 M Feb. 21, 1894

Name.	Address.	Date of Membership.
Goldsborough, Winder Elwell, *M. E.*,	Professor of Electrical Engineering and Director of Electrical Laboratory, Purdue University, 113 South St., Lafayette, Ind.	A Mar. 21, 1893 M Jan. 25, 1899
Goltz, William	Badt-Goltz Engineering Co., 1504 Monadnock Block, Chicago, Ill.	A Oct. 27, 1897 M Feb. 23, 1898
Goodman, Wm. Geo. Toop	Electrical Engineer, Tramway Construction under N.S W. Government, Public Works Dep't;residence, 86 Bondi Road, Sydney, N.S.W.	A Aug. 23, 1899 M May 15, 1900
Gossler, Philip Green	Electrical Engineer, Royal Electric Co., 94 Queen St., Montreal, P.Q.	A June 20, 1894 M June 24, 1898
Gregg, Tom Howard	Supt. Electrical Construction, U. S. Light House Board, Tompkinsville, S. I., N. Y.; residence, 6 Wall St., St. George, S. I.	A Mar. 22, 1899 M Sept. 26, 1900
Gutmann, Ludwig	Consulting Electrical Engineer, 309 Y. M. C. A. Building, Peoria, Ill.	A Sept. 14, 1888 M Mar. 21, 1893
Hadaway, W. S., Jr.	Electric Heating Engineer, 107 Liberty St., New York City.	A Nov. 21, 1894 M Oct. 21, 1896
Hadley, Arthur L.	Electrical Engineer, Fort Wayne Electric Works, residence, 252 W. DeWald St, Fort Wayne, Ind	A Oct. 17, 1894 M Mar. 22, 1901
Hadley, Fred'k W. [Life Member.]	Electrical Eng'r, c/o Westinghouse, Church, Kerr & Co., 26 Cortlandt St, New York; residence, Arlington Heights, Mass.	A Aug. 5, 1896 M Feb. 28, 1901
Hafer, George, Jr.,	Gen. Supt. and Elec. Eng. Cincinnati Gas Co., Elect. Dept., Cincinnati, O.	A Nov. 23, 1900 M Apr. 26, 1901
Hall, Clayton C.	Attorney-at-Law, and Consulting Actuary, Room 40, Maryland Life Building, 10 South St., Baltimore, Md.	A April 15, 1884 M Oct. 21, 1884
Hall, John L.	District Manager, Bullock Electric M'f'g. Co., 608-609 North American Bldg.; residence, 3116 Euclid Ave., Philadelphia, Pa.	A Sept. 22, 1891 M Dec. 20, 1893
Hamilton, Geo. A.	(*Treasurer.*) Electrician, Western Electric Co., 463 West Street, New York; residence, 532 Morris Ave., Elizabeth, N. J.	A April 15, 1884 M Oct. 21, 1884
Hammer, Edwin W	Electrical Engineer, 46 Second Ave., Newark, N. J.	A Nov. 18, 1896 M June 23, 1897
Hammer, William J. [Life Member.]	Consulting and Supervising Electrical Engineer, 1406 Havemeyer Bldg, 26 Cortlandt St., [Tel. 251 Cortlandt]; residence, 153 West 46th St., New York City.	A June 8, 1887 M July 12, 1887
Hanchett, Geo. T.	Electrical and Technical Engineer, 123 Liberty St., N. Y.; residence, Hackensack, N. J.	A May 19, 1896 M Feb 15, 1899

Name.	Address.	Date of Membership.
Harrington, Walter E.	Electric Railway Engineer, 200 Market St.; residence, 554 Haddon Ave., Camden, N. J.	A Mar. 17, 1891 M May 19, 1899
Hartwell, Arthur	Manager Chicago office, Westinghouse Electric and Mfg. Co.; 171 La Salle Street, Chicago, Ill	A May 15, 1894 M Nov. 20, 1895
Haskins, Caryl D.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	A Mar, 18, 1890 M June 20, 1894
Haskins, Charles H.	Electrician, 70 Linwood Avenue, Buffalo, N. Y.	A April 15, 1884 M Oct. 21, 1884
Haskins, Clark Caryl	Electrical Engineer, 682a West Adams St., Chicago, Ill.	A Sept. 20, 1893 M Mar. 21, 1894
Hasson, W. F. C.	Consulting Engineer, Judd Building Honolulu, H.I.	A Mar. 18, 1890 M May 15, 1894
Hayes, Hammond V.	Electrical Engineer, the American Bell Telephone Co., 125 Milk St., So. Boston; residence, Cambridge, Mass.	A Nov. 12, 1889 M Mar. 18, 1890
Hayes, Harry E.	Asst. Electrician, American Telegraph and Telephone Co., 22 Thames St., New York City.	A April 18, 1893 M Dec. 20, 1893
Haynes, F. T. J.	Divisional Telegraph Engineer, Great Western Railway; residence, Belmont Villa, Cheddon Road, Taunton, Eng.	A Dec. 6, 1886 M Jan. 3, 1887
Heath, Harry E.	Chief Engineer, Eddy Electric M'f'g. Co., Windsor, Conn.	A Mar. 21, 1893 M Mar. 25, 1896
Heinrich, Richard O.	General Manager, European Weston Electrical Instrument Co., 88 Ritterstrasse, Berlin, Germany.	A Oct. 1, 1889 M Oct. 25, 1892
Henshaw, Frederick V.	Ass't. Engineer, Crocker-Wheeler Co., Ampere, N. J.; residence, 79 State St., Brooklyn, N. Y.	A Feb. 5, 1889 M Nov. 20, 1895
Herdman, Frank E.	Mechanical and Electrical Engineer, Crane Elevator Co., Winnetka, Ill.	A Dec. 18, 1895 M Oct. 21, 1896
Hering, Carl [Life Member.]	(*President.*) Consulting Electrical Engineer, 929 Chestnut St.; Philadelphia, residence, Lehman Lane, Germantown, Pa.	A Jan. 3, 1888 M June 5, 1888
Herrick, Charles H.	Superintendent Isolated, Lighting and Power Dep't., Edison Electric Illuminating Co., 3 Head Place, Boston; residence, 22 Herrick St., Winchester, Mass.	A April 21, 1891 M Jan. 17, 1893
Herzog, F. Benedict, *Ph. D.*	President, Herzog Teleseme Co., 51 W. 24th St., New York City.	A May 24, 1887 M July 12 1887
Hewitt, Charles	Electrical Engineer, Union Traction Co., 809 Spruce Street, Philadelphia, Pa.	A Sept. 16, 1890 M May 17, 1892
Hewlett, Ernest Holcombe	c/o Institution of Electrical Engineers, 28 Victoria St., Westminster, London, England.	A Aug. 23, 1899 M. Dec. 27, 1899

Name.	Address.	Date of Membership.
Hibbard, Angus S.	General Manager. Chicago Telephone Co., 203 Washington St., Chicago, Ill.	A Nov. 24. 1891 M Feb. 16, 1892
Higgins, Edward E.	Treasurer McGraw-Marden Co , 32 Waverly Place, New York City ; residence, Tarrytown, N. Y.	A June 8, 1887 M July 12, 1887
Hobart, Henry M.	Engineer, care Union Electricitats Gesellschaft, Berlin, Germany.	A April 18, 1894 M Sept. 27, 1899
Holmes, Franklin S.	Electrical Engineer, 108 Fulton St., New York City ; residence 318 E. 12th St., Brooklyn, N. Y.	A April 21, 1891 M June 20, 1894
Houston, Edwin J., *Ph.D.* (*Past President.*) [Life Member.]	Prof. of Physics, Franklin Inst., Firm of Houston & Kennelly, Crozer Bldg., 1420 Chestnut St. ; residence, 1809 Spring Garden St., Phila., Pa.	A April 15, 1884 M Oct. 21, 1884
Howell, John W.	Engineer, Lamp Works General Electric Co. Harrison; residence, Ballantine Parkway, Newark, N.J.	A July 12, 1887 M June 5, 1888
Howell, Wilson S.	Test Officer, Lamp Testing Bureau, 5th and Sussex Sts , Harrison; residence, Ward Place, South Orange, N. J.	A Sept. 3, 1889 M Mar. 18. 1890
Hubley, George Wilbur	Superintendent and Electrical Engineer Louisville Electric Light Co.; residence, 1205 Garvin Place, Louisville, Ky.	A Sept 19. 1894 M May 15. 1900
Humphrey, Henry H.	Consulting Electrical Engineer, Suite 1305 Chemical Building, St Louis, Mo.	A Dec. 16, 1896 M April 28, 1897
Hunter, Rudolph M.	Expert and Counsellor in Patent Causes, 926 Walnut St., Philadelphia, Pa.	A July 13, 1886 M May 17, 1887
Hunting, Fred S.	Chief Engineer, Engineering Department, Fort Wayne Electric Co., 325 West Washington St., Fort Wayne, Ind.	A Nov. 15, 1892 M May 16, 1893
Hutchinson, Dr. Cary Talcott [Life Member.]	Consulting Electrical Engineer, 71 Broadway, New York City.	A Feb. 7, 1890 M Dec. 16, 1890
Hyde, Jerome W.	Ass't Treasurer, The Springfield Steam Power Co., Wason Bldg. Springfield, Mass.	A June 8, 1887 M Nov. 1, 1887
Inrig, Alec Gavan	Globe Electrical Co., Arthur Villa, Agnes Road, Blundellsands, near Liverpool, Eng.	A Jan. 19, 1892 M May 17, 1892
Ives, Edward B.	Signal Officer, U. S. Volunteers, War Dept., Washington, D. C.	A April 2, 1889 M May 15, 1894
Jackson, Dugald C.	Consulting Engineer, Professor of Electrical Engineering, University of Wisconsin, Madison, Wis.	A May 3, 1887 M June 17, 1890
Jackson, Francis E.	Incandescent Filaments Manufacturer, 128 Essex Ave., Orange; residence, 61 South Grove St., East Orange, N. J.	A Jan. 3, 1888 M June 17, 1890

Name.	Address.	Date of Membership.
JACKSON, HENRY	Telegraph Supt. and Engineer, The Lancashire & Yorkshire Railway Co., Horwich, Bolton-le-Moors, Lancashire, England.	A Mar. 21, 1894 M Dec. 19, 1894
JACKSON, JOHN PRICE	Professor of Electrical Engineering, Penn. State College, State College, Pa.	A Sept. 27, 1892 M Jan. 17, 1894
JACKSON, WM. B.	Engineer, with Stanley Electric M'f'g Co., Pittsfield, Mass.	A Aug. 13, 1897 M June 24, 1898
JANNUS, FRANKLAND	Attorney-at-Law, Solicitor of Patents, Room 1113: 141 Broadway, (Tel 6273 Cortlandt), New York City.	A Nov. 12, 1889 M Mar. 18, 1890
JEHL, FRANCIS	VII Kazinczy-uteza 21, Budapest, Hungary.	A June 27, 1895 M Jan. 22, 1896
JENKS, W. J.	Secretary, Board of Patent Control, 120 Broadway, New York City; residence, 497 4th St., Brooklyn, N. Y.	A June 8, 1887 M Nov. 1, 1887
JOHNSTON, A. LANGSTAFF	Chief Engineer, Richmond Traction Co., 1112 E. Main St., Richmond, Va.	A April 21, 1891 M April 18, 1894
JONES, FRANCIS WILEY [Life Member.]	Electrical Engineer, Postal Telegraph-Cable Co., 253 Broadway, New York City.	A April 15, 1884 M Oct. 21, 1884
KEITH, DR NATHANIEL S.	Chief Engineer and Electro-Metallurgist, Arlington Copper Co., Telephone 19 "Arlington," Arlington, N. J.	A April 15, 1884 M Jan. 17, 1894
KENAN, WM. R. JR.	c/o Traders' Paper Co., Lockport, N. Y.	A Jan. 20, 1897 M Apr. 26, 1901
KENNELLY, ARTHUR E. [Life Member.]	(*Past-President*)Electricial Engineer, Firm of Houston & Kennelly, 1203-4 Crozer Bldg., 1420 Chestnut St.; residence, The Landsowne, N. 41st St. and Parkside Ave., Philadelphia, Pa.	A May 1, 1888 M May 16, 1899
KIRKLAND, JOHN W.	c/o So. African General Electric Co., Hampson's Building, Durban, Natal, S. Africa.	A Mar. 21, 1894 M Sept. 26, 1900
KINSMAN, FRANK E.	Electrical Engineer, 26 Cortlandt St., New York City; residence, 836 Sherman Ave., Tel. 1024, Plainfield, N. J.	A Sept 27, 1892 M May 16, 1893
KNOWLES, EDWARD R.	*E. E.*, *C. E.* Consulting Electrical Engineer, 136 Liberty St., New York City; residence, 82 Cambridge Place, Brooklyn, N. Y.	A June 8, 1887 M July 12, 1887
KNOX, CHAS. EDWIN	With C. O. Mailloux, Consulting Electrical Engineer, 76 William St.; residence, 108 W. 122nd St., New York, N. Y.	A. May 16, 1899 M. Dec. 27, 1899
KNUDSON, A. A.	Electrical Engineer, Room 416, 32 Nassau St., New York City, Telephone 2100 John; residence, 127 Prospect Place, Rutherford, N. J.	A Dec. 6, 1887 M Jan. 3, 1888

Name.	Address.	Date of Membership.
Lange, Philip A.	Superintendent Westinghouse Electric and Manufacturing Co., East Pittsburg, Pa.	A Mar 6, 1888 M June 5, 1888
Langton, John	Electrical Engineer, Canada Life Building, Toronto, Ont., and 72 Trinity Place, New York, N. Y.	A Mar. 6, 1888 M June 5, 1888
Lardner, Henry Ackley	J. G. White & Co., 29 Broadway, New York City; residence, 50 Orange St., Brooklyn, N. Y.	A Dec. 19, 1894 M May 16, 1899
La Roche, Fred. A.	Senior Member of F. A. La Roche & Co., 652–660 Hudson Street; residence, 28 W. 25th St., New York.	A Sept. 19, 1894 M Nov. 20, 1895
Layman, W. A.	Assistant Manager and Treasurer, Wagner Electric M'f'g. Co., 2017 Locust St. St. Louis, Mo.	A Nov. 22, 1899 M Nov. 23, 1900
Lemp, Hermann, Jr.	Electrician, General Electric Co.; residence, 186 Allen Ave., Lynn, Mass.	A April 2, 1889 M Feb. 21, 1893
Leonard, H. Ward [Life Member.]	Electrical Engineer, Pres't. Ward Leonard Electric Co., Bronxville, N Y.; residence, Lawrence Park, N. Y.	A July 12, 1887 M Sept. 6, 1887
Leslie, Edward Andrew	Vice-President and Manager, Manhattan Electric Light Co., Ltd., 57 Duane Street. New York City; residence, 262 Hancock Street, Brooklyn, N. Y.	A Jan. 16, 1895 M Feb. 17, 1897
Levis, Minford	Superintendent and Electrical Engineer, Novelty Electric Co., 54 North 4th St., Philadelphia, Pa.	A Feb. 21, 1893 M June 23, 1897
Leyden, Harry Russell,	Hamilton Elec. Lt. & Cataract Pr. Co., Mgr , Hamilton, Ont.	A Nov. 23, 1900 M Feb. 28, 1901
Lieb, John William, Jr.	(*Vice-President*) General Mgr., Edison Electric Ill. Co., 53 Duane St.; residence, 869 West End Ave., New York City.	A Sept. 6, 1887 M Nov. 1, 1887
Lighthipe, James A.	District Engineer, General Electric Co., Claus Spreckels Bldg., San Francisco, Cal.	A Feb. 21, 1894 M April 17, 1895
Lincoln, Paul M.	Electrical Supt. Niagara Falls Power Co., Niagara Falls, N. Y.	A Sept. 25, 1895 M June 24, 1898
Lloyd, Herbert	(*Manager*) Vice President and General Manager, Electrical Engineer and Chemist, The Electric Storage Battery Co., Allegheny Ave. and 19th St , Philadelphia, Pa.	A June 20, 1894 M May 21, 1895
Lloyd, John E.	Chief Engineer and General Manager Cape Town Tramways, 49 Sir Lowry Road, Cape Town, S. Africa.	A Jan. 22, 1896 M Mar. 25, 1896
Lloyd, Robert McA.	Electrician, 100 Broadway; residence, 5 Gramercy Park, New York City.	A Oct. 21, 1890 M Nov. 15, 1893

Name.	Address.	Date of Membership.
LOCKWOOD, THOMAS D., [Life Member.]	Electrical Engineer, and Advisory Electrician, P. O. Drawer 2, Boston, Mass.	A April 15, 1884 M Oct. 21, 1884
LOOMIS, OSBORN P.	Electrical Engineer, Newport News Shipbuilding and Dry Dock Co., Newport News, Va.	A Sept. 16, 1890 M Dec. 16, 1896
LORRAIN, JAMES GRIEVE	Norfolk House, Norfolk St., London, W. C., England.	A May 16, 1891 M May 15, 1894
LOVEJOY, J. R.	General Manager, Supply Dept., General Electric Co., Schenectady, N. Y.	A April 21, 1891 M Feb. 21, 1894
LOZIER, ROBERT T. E.	Manager, Bullock Electric Co., St. Paul Bldg., New York City; residence, 326 Richmond Terrace, New Brighton, S. I.	A May 20, 1890 M Jan. 24, 1900
LYMAN, JAMES [Life Member.]	Assistant Engineer, Chicago Office, General Electric Co., Monadnock B'ld'g., Chicago; residence, 1308 Maple Ave., Evanston, Ill.	A Sept. 19, 1894 M Jan. 9, 1901
MACCOUN, ANDREW ELLICOTT	Supt. of the Electrical Dep't., The Carnegie Steel Co., Braddock, Pa.	A Nov. 20, 1895 M July 18, 1899
MACFARLANE, ALEXANDER, *D. Sc.*, *LL.D.*	Lecturer on Mathematical Physics, Lehigh University, South Bethlehem, Pa.	A Jan. 19, 1892 M May 17, 1892
MAILLOUX, C. O. [Life Member.]	(*Manager*) Consulting Electrical Engineer, 76 William St., Telephone 2776 John; residence, 48 W. 73d St., New York.	A April 15, 1884 M Oct. 21, 1884
MANSFIELD, ARTHUR N.	With American Telephone and Telegraph Co., 125 Milk St., Boston, Mass.	A Dec. 20, 1893 M June 20, 1894
MARKS, LOUIS B., *M. M. E.*	President, Marks Enclosed Arc Light Co., 689 Broadway; residence, 51 East 67th St., New York City.	A May 20, 1890 M Jan. 16, 1895
MARKS, WILLIAM DENNIS, *Ph.B. C. E.*	President, The American Electric Meter Co., 9th & Montgomery Ave., Phila.; Pres. City Heat and Light Co., Fostoria, O.; Mail, Art Club, Phila., Pa.	A Feb. 7, 1888 M May 1, 1888
MARSHALL, J. T.	Metuchen, N. J.	A Oct. 1, 1889 M Nov. 12, 1889
MARTIN, JULIUS	Master Electrician, Navy Yard, Brooklyn; residence, 445 W. 21st St., New York City.	A Oct. 21, 1890 M Nov. 20, 1895
MARVIN, HARRY N.	c/o American Mutoscope and Biograph Co., 841 Broadway, New York City.	A April 19, 1892 M Jan. 17, 1893
MAVER, WILLIAM, JR.	Electrical Expert and Consulting Electrical Eng'r, 120 Liberty St., New York City; residence, 227 Arlington Ave. (Tel. 1282 Bergen) Jersey City, N. J.	A July 12, 1887 M April 21, 1891

Name.	Address.	Date of Membership.
MAYER, GEORGE M.	Mechanical and Electrical Engineer, 1401 Monadnock Bldg., Chicago, Ill.	A Dec. 16, 1890 M June 20, 1894
MAYNARD, GEO. C.	Electrical Engineer, Smithsonian Institution, Washington, D. C.	A April 15, 1884 M Dec. 9, 1888
McCAY, H. KENT	Electrical Engineer and Contractor, 106 E. German St., Baltimore, Md.	A Sept. 16, 1890 M May 19, 1891
McCROSKY, JAMES W.	Chief Engineer, La Capital Tramway Co. and Compañia de Luz y Fuerza Motriz de Cordoba, Reconquista 20, Buenos Aires, Argentina.	A Dec. 20, 1893 M Dec. 16, 1896
McCROSSAN, J. A.	Manager and Electrician, Citizens' Telephone and Electric Co., Rat Portage, Ont.	A Oct. 18, 1893 M Dec. 18, 1895
MERSHON, RALPH D.	(*Manager.*) Consulting Engineer, Room, 840, 621 Broadway, New York City.	A Mar. 20, 1895 M Jan. 22, 1896
MILLIS, JOHN	Major of Engineers U. S. A., Seattle, Wash.	A July 7, 1884 M Mar. 3, 1885
MITCHELL, JAMES [Life Member.]	Constructing Engineer and Agent, General Electric Co., Caixa do Correio No. 954, Rio de Janeiro, Brazil.	A Sept. 25, 1895 M Mar. 25, 1896
MIX, EDGAR W.	Electrical Engineer, 12 Boulevard des Invalides, Paris, France.	A Sept. 3, 1889 M Mar. 20, 1895
MOLERA, E. J.	Civil and Electrical Engineer, 2025 Sacramento St., San Francisco, Cal.	A Jan. 16, 1892 M June 7, 1892
MOORE, D. McFARLAN	Inventor, Moore Electrical Co., 52 Lawrence St., Newark, N. J.	A Dec. 20, 1893 M June 20, 1894
MOORE, WM. E.	General Superintendent and Electrician, The Augusta Railway & Electric Co., Augusta, Ga.	A Jan. 22, 1896 M Sept. 27, 1899
MORROW, JOHN THOMAS	Supt. Electrolytic Plant, Boston and Montana Consolidated Copper and Silver Mining Co., Great Falls, Mont.	A Dec. 21, 1892 M April 18, 1894
MURPHY, JOHN	Superintendent Power Houses, The Ottawa Electric Co., Ottawa, Ont.	A May 15, 1900 M Apr. 26, 1901
NEILER, SAMUEL G.	Member of the Firm of Pierce, Richardson & Neiler, Consulting and Designing Engineers, 1405 – 12 Manhattan Building; residence, Hotel Del Prado, Chicago, Ill.	A April 18, 1894 M Dec. 18, 1895
NICHOLS, DR. EDWARD L.	Professor of Physics, Cornell University; residence, 5 South Ave., Ithaca, N. Y.	A Oct. 4, 1887 M Dec. 6, 1887
NICHOLSON, WALTER W.	General Supt. Central N. Y. Telephone and Telegraph Co., Telephone Building, Utica, N. Y.	A May 15, 1894 M May 18, 1897
NOLL, AUGUSTUS	Contracting Electrical Engineer, 8 East 17th St., Telephone, 62, 18th; New York City.	A Sept. 27, 1892 M April 18, 1893

Name.	Address.	Date of Membership.
Nunn, Paul N.	Chief Engineer, Telluride Power Co., Telluride, Colo.	A April 17, 1895 M Feb. 26, 1895
O'Connell, Joseph J.	Telephone Engineer, Chicago Telephone Co., Residence, 76 Eugene St., Chicago, Ill.	A Oct. 17, 1894 M Nov. 20, 1895
O'Dea, Michael Torpey	[Address unknown.]	A June 8, 1887 M Mar 25, 1896
Oudin, Maurice A.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	A June 20, 1894 M Nov. 20, 1895
Owens, Robert Bowie	McDonald Professor of Electrical Engineering, McGill University, Montreal, P.Q.	A June 17, 1890 M Dec. 15, 1897
Paine, F. B. H.	Westinghouse Electric and Mfg. Co., 120 Broadway, New York, N. Y.	A Dec. 16, 1890 M Nov. 25, 1891
Paine, Sidney B.	General Electric Co., 180 Summer St., Boston, Mass.	A June 8, 1887 M Nov. 1, 1887
Parker, Lee Hamilton	The Buenos Aires and Belgrano Electric Tramways Co., Calle Santa Fé No. 2457, Buenos Aires.	A Aug. 5, 1895 M Dec. 16, 1896
Parks, C. Wellman	Civil Engineer, U. S. N., U. S. Naval Station, San Juan, P. R.	A July 12, 1887 M May 1, 1888
Parshall, Horace Field	Consulting Engineer, 8 Princes St. Bank, E. C., London, Eng.	A Sept. 7, 1888 M Mar. 18, 1890
Pattison, Frank A.	Firm of Pattison Bros, Consulting and Constructing Electrical Engineers, 141 Broadway, New York City.	A Sept. 22, 1891 M Dec. 16, 1891
Pearson, F. S.	Engineer, Room 841, 621 Broadway, New York City.	A Oct. 25, 1892 M Feb. 21, 1893
Peck, John Sedgwick	Electrical Designer, The Westinghouse E. & M. Co., Pittsburg, Pa.	A Apr. 26, 1899 M May 15, 1900
Pedersen, Frederick Malling, *M. I.*, *E. E.*	Instructor in Mathematics, College of the City of New York, 17 Lexington Ave.; residence, 39 Washington Square, New York City.	A Sept. 20, 1893 M June 24, 1898
Perot, L. Knowles	President of The Schuylkill Valley Illuminating Co., Phœnixville, Pa.	A Mar. 15, 1892 M Dec. 18, 1895
Perrine, Frederic A. C., *D. Sc.*	President Stanley Electric M'f'g Co., Pittsfield, Mass.	A Sept. 16, 1890 M Dec. 16, 1890
Pickernell, F. A.	Chief Engineer, Amer. Tel. & Tel. Co., 22 Thames St., New York City.	A Feb. 7, 1890 M Mar. 18, 1890
Pierce, Richard H.	Pierce, Richardson & Neiler, Electrical Engineers, 1409 and 1410 Manhattan Bldg., Chicago; residence, 5434 Monroe Ave., Hyde Park, Ill.	A April 18, 1893 M Dec. 20, 1893
Pike, Clayton W., *B.S.*	Electrical Engineer, Keller, Pike & Co., 112 N. 12th St., Philadelphia, Pa.	A Dec. 16, 1891 M Oct. 25, 1892

Name.	Address.	Date of Membership.
Porter, Joseph F.	(*C. E.*) President and Managing Engineer, Alton Railway, Gas and Electric Co., Alton, Ill.	A Sept. 6, 1887 M Nov. 1, 1887
Potter, Wm. Bancroft,	Engineer Railway Dept., General Electric Co., Schenectady, N. Y.	A Jan. 22, 1896 M Mar. 25, 1896
Pratt, Robert J.	Electrician, Honolulu Iron Works, Honolulu, H. I.	A July 12, 1887 M Sept. 6, 1887
Puffer, Wm. L.	Assistant Professor of Electrical Engineering, Mass. Institute of Technology, Boston; residence, West Newton, Mass.	A Dec. 20, 1893 M April 17, 1895
Rae, Frank B.	Consulting Electrical and Mechanical Engineer, 45 Broadway, New York City.	A April 15, 1884 M Oct. 25, 1892
Reber, Samuel	Lieut. Col. Signal Corps, U. S., Governor's Island, New York City.	A Sept. 20, 1893 M Jan. 22, 1896
Reckenzaun, Frederick,	Electrical Engineer, 44 Pine St., New York City.	A Mar. 6, 1888 M June 5, 1888
Redman, Geo. A.	General Supt., Electric Dept., Brush Elec. Light Co., and Rochester Gas and Elec. Co., 82 Andrews St.; residence, 30 Park Ave., Rochester, N. Y.	A Feb. 27, 1895 M May 17, 1898
Reid, Thorburn	Consulting Electrical Engineer, 136 Liberty St., New York City.	A Oct. 21, 1890 M June 24, 1898
Reist, Henry G	Designing Engineer, General Electric Co., 5 South Church St., Schenectady, N. Y.	A June 17, 1890 M Dec, 19, 1894
Reno, C. Stowe	Electrical Engineer, Triumph Electric Co., 620 Baymiller Street, Cincinnati, Ohio.	A Nov. 23, 1898 M July 18, 1899
Rice, Calvin Winsor	(*Manager.*) Electrical Engineer, Edison Electric Illuminating Co. of New York. Electrician, Consolidated Telegraph and Electrical Subway Co., 57 Duane St., New York City.	A Jan. 20, 1897 M April 28, 1897
Rice, E. Wilbur, Jr.	Technical Director, The General Electric Co., Schenectady, N. Y.	A Dec. 6, 1887 M Jan. 3, 1888
Richardson, Robert E.	Vice-President of Pierce, Richardson & Neiler, 1409 Manhattan Building residence, 88 E. 34th St., Chicago, Ill. General Manager, Kansas City, (Mo.) Electric Light Co.	A Sept. 19, 1894 M May 18, 1897
Ridley, A. E. Brooke	Electrical Engineer and Contractor, Parrot B'ldg. San Francisco, Cal.	A Nov. 21, 1894 M Nov. 23, 1898
Ries, Elias E.	Electrical Engineer and Inventor, 1242 New York Life Insurance Bldg.; residence, 4 W. 115th St., New York City.	A July 12, 1887 M Sept. 6, 1887

Name.	Address.	Date of Membership.
Riker, Andrew L. [Life Member.]	Electrical Engineer, The Riker Electric Vehicle Co, Elizabethport, N. J.	A Nov. 1, 1887 M Dec. 18, 1895
Robb, Russell	With Stone & Webster, 93 Federal Street, Boston, Mass.	A Oct. 18, 1893 M May 21, 1895
Robb, Wm. Lispenard	Professor of Physics, Trinity College, and 118 Vernon St., Hartford, Conn.	A Dec. 16, 1891 M Mar. 15, 1892
Roberts, E. P.	E. P. Roberts & Co., Consulting Engineers, Electric Building, Telephone 2656; residence, 95 Cornell St., Cleveland, O.	A Jan. 6, 1885 M Feb. 3, 1885
Rodgers, Howard S.	Electrical Engineer, care General Electric Co., 420 W. 4th Street, Cincinnati, O.; residence, 190 E. 2d St., Covington, Ky.	A Sept. 27, 1892 M May 16, 1893
Rohrer, Albert L.	Electrical Supt. Schenectady Works General Electric Co.; residence, 20 Union St., Schenectady, N. Y.	A Nov. 1, 1887 M May 1, 1888
Roller, John E.	Lieut. Commander U. S. N., Navy Department, Washington, D. C.	A Sept. 19, 1894 M May 19, 1896
Rosa, Edward B.	Professor of Physics, Wesleyan University, Middletown, Conn.	A Feb. 17, 1897 M May 18, 1897
Ross, Norman N.	Electrical Engineer, c/o General Post Office, Boston, Mass.	A Sept. 20, 1893 M Nov. 21, 1894
Ross, Robert A.	Mechanical and Electrical Consulting Engineer, 17 St. John St., Montreal, P. Q.	A Sept. 27, 1892 M April 18, 1893
Rouquette, William F. B. [Life Member.]	Proprietor, Rouquette & Co., 47 Dey St., New York City.	A Mar. 21, 1894 M Dec. 19, 1894
Ryan, Harris, J.	Professor of Electrical Engineering, Cornell University; residence, Cascadilla Place, Ithaca, N. Y.	A Oct. 4, 1887 M April 17, 1895
Sachs, Joseph	Electrical Engineer, The Johns-Pratt Company; residence, 220 Collins St., Hartford Conn.	A Mar. 15, 1892 M Dec. 15, 1897
Salomons, *Sir* David Lionel, *Bart. M. A.*, [Life Member]	Engineer and Barrister, Broomhill, Tunbridge Wells, Kent, and 49 Grosvenor St., London, W. England.	A Feb. 7, 1888 M May 1, 1888
Sampson, F. D.	Manager, Charlotte Electric Light and Power Co., Charlotte, N. C.	A Aug. 5, 1896 M Oct. 27, 1897
Sands, H. S.	Consulting and Constructing Electrical Engineer, 1153 Market St., Wheeling, W. Va.	A Feb. 21, 1893 M Nov. 21, 1894
Sargent, William D.	Vice Prest. and General Manager, N. Y. & N. J. Tel. Co., 81 Willoughby St.; residence, 820 Union St., Brooklyn, N. Y.	A April 15, 1884 M Feb. 21, 1894
Scheffler, Fred. A.	Manager, Water Tube Boiler Dept., James Beggs & Co, 9 Dey St., N. Y. City; residence, 33 Snowden Pl., Glen Ridge, N. J.	A May 16, 1893 M Jan. 26, 1896

Name.	Address.	Date of Membership.
SCHMID, ALBERT	Directen Genèral de la Sociètè Industrielle d'Electricitè procèdès Westinghouse, 45 rue de l'Arcade Paris, France.	A Oct. 21, 1890 M April 17, 1895
SCHOEN, A. M.	Electrician, South Eastern Tariff Association, 339 Equitable Building, Atlanta, Ga.	A Sept. 20, 1893 M Dec. 16, 1896
SCHWEDTMANN, FERDINAND	General Sup't Wagner Electric M'f'g Co., 2017 Locust St., St. Louis, Mo.	A Nov. 22, 1899 M Nov. 23, 1900
SCOTT, CHARLES F.	Chief Electrician, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	A April 19, 1892 M Jan. 17, 1893
SCOTT, JAMES B.	Consulting Electrical, and Mechanical Engineer. 227 East German St.; rèsidence. 847 Ducatel St,, Baltimore Md.	A Aug. 5, 1896 M May 17, 1898
SEVER, GEORGE FRANCIS	(*Manager.*) Adj. Prof. of Electrical Engineering, Columbia University, New York City.	A Jan. 17, 1894 M May 19, 1896
SHAW, EDWIN C.	Mechanical Engineer, The B. F. Goodrich Co., Akron, O.	A May 17, 1892 M Feb. 27, 1895
SHEA, DANIEL W.	Professor of Physics, Catholic University of America, Washington, D. C.	A Dec. 20, 1893 M June 20, 1894
SHELDON, SAMUEL, *A. M., Ph.D.* (*Manager.*) [Life Member.]	Professor of Physics and Electrical Engineering, Polytechnic Institute, 198½ Schermerhorn St., Brooklyn, N.Y.	A Dec. 16, 1890 M Oct. 27, 1891
SHEPARDSON, GEORGE D.	Professor of Electrical Engineering, University of Minnesota, Minneapolis, Minn.	A April 21, 1891 M Jan. 22, 1896
SINCLAIR, H. A.	Electrical Engineer, The Tucker Electric Co., 35 South William St., New York; 950 Bedford Ave. Brooklyn, N. Y.	A June 17, 1890 M Feb. 26, 1896
SMITH, FRANK E.	Consulting and Supervising Electrical Engineer, 183 Jessie St.; residence, 418 Eugenia Ave., San Francisco, Cal.	A Sept 19, 1894 M July 18, 1899
SMITH, FRANK STUART	Manager, Sawyer-Man Electric Co. Allegheny, Pa.	A Sept. 27, 1892 M April 18, 1893
SMITH, HAROLD BABBITT	Professor of Electrical Engineering, Worcester Polytechnic Institute; residence, 20 Trowbridge Road, Worcester, Mass.	A Nov. 24, 1891 M April 25, 1900
SMITH, JESSE M.	Expert in Patent Causes, Consulting Electrical and Mechanical Engineer, 36 Moffat Block, Detroit, Mich., and 218 Broadway, New York City.	A April 15, 1884 M June 26, 1891
SMITH, T. CARPENTER	Member of Firm of M. R. Muckle, Jr., & Co., 650 Drexel Bldg.; residence. The "Newport," Philadelphia, Pa.	A Oct. 27, 1891 M Dec. 16, 1891

Name.	Address.	Date of Membership.
Spaulding, Hollon C.	Contracting Engineer, American Stoker Co., 176 Federal Steet, Boston; residence, 15 Park Vale, Brookline, Mass.	A April 21, 1891 M June 20, 1894
Sperry, Elmer A.	Electrical Engineer, 855 Case Ave., Cleveland, O.	A April 19, 1892 M Feb. 21, 1893
Sprague, Frank J.	(*Past-President.*) Consulting Engineer, Sprague Electric Co., 20 Broad St.; residence, 305 West 80th St., New York City	A May 24, 1887 M Feb. 17, 1897
Springer, Frank W.	Assistant Professor Electrical Engineering, University of Minn., Minneapolis, Minn	A Nov. 23, 1900 M Apr. 26, 1901
Stanley, William	Electrical Engineer and Inventor, Great Barrington, Mass.	A Dec. 6, 1887 M Oct. 26, 1898
Stearns, Charles K. *E.E.*	93 Federal St., and 85 Westland Avenue, Boston, Mass.	A Aug. 6, 1889 M May 16, 1893
Stearns, Joel W., Jr.	Treasurer, Mountain Electric Co., Box 1531, Denver, Col.	A June 20, 1894 M Nov. 20, 1895
Stebbins, Theodore	Engineer of Committee on Local Companies, General Electric Co., Schenectady, N. Y.	A July 9, 1889 M June 17, 1890
Steinmetz, Charles P.	(*Manager.*) Electrician, General Electric Co., Schenectady, N. Y.	A Mar. 18, 1890 M April 21, 1891
Stephens, George	Societe des Establissements Postel-Vinay, 219 Rue de Vangirad, Paris, France	A June 20, 1894 M Dec. 18, 1895
Stevens, J. Franklin	President Keystone Electrical Instrument Co., 9th St. and Montgomery Ave.; Philadelphia, Pa.	A Sept. 19, 1894 M Feb. 28, 1901
Stewart, Robert Stuart	Westinghouse Electric and Mfg., Co., 440 Jefferson Ave., Detroit, Michigan.	A Dec. 20, 1896 M May 15, 1900
Stieringer, Luther	Electrical Expert, 129 Greenwich St., New York City.	A June 8, 1887 M Nov. 1, 1887
Stillwell, Lewis B.	(*Vice-President.*) Consulting Electrical Engineer, Electrical Director, Rapid Transit Subway Construction Co., Park Row Bldg., New York City.	A April 19, 1892 M Nov. 15, 1892
Storrs, Prof. H. A.	U. S. Assistant Engineer, Post Office Bldg.; residence, 45 William St., New London, Ct.	A Mar. 21, 1893 M Jan. 24, 1900
Stott, Henry G.	Supt. Motive Power, Manhattan Railway Co., New York.	A Sept. 25, 1895 M April 22, 1896
Strong, Frederick G.	Box, 959, Hartford, Conn.	A Oct. 27, 1891 M July 18, 1899
Taintor, Giles	Sup't. Right of Way Department, New England Telephone and Telegraph Co., 125 Milk St.; residence, 34½ Shepard St., Cambridge, Boston, Mass.	A June 26, 1891 M Dec. 16, 1891

Name.	Address.	Date of Membership.
TERRY, CHARLES A.	Lawyer, Westinghouse Electric and Mfg. Co., 120 Broadway, New York City.	A April 5, 1887 M May 17, 1887
THEBERATH, THEODORE E.	Supt. Yuba Division, Bay Counties Power Co., Marysville, Cal.	A Mar. 23, 1898 M June 24, 1898
THOMAS, BENJAMIN F.,	Professor of Physics, Ohio State University, Columbus, O.	A June 7, 1892 M Nov. 15, 1892
THOMSON, ELIHU	(*Past President*). Electrician, General Electric, and Thomson Electric Welding Companies, Lynn, residence, 22 Monument Ave., Swampscott, Mass.	A April 15, 1884 M April 21, 1891
THOMPSON, EDWARD P.	Solicitor of Patents, and Expert, 156 Fifth Ave., cor. 20th Street, residence, 1 Gramercy Park, New York City.	A April 15, 1884 M Dec. 3, 1889
THRESHER, ALFRED A.	Electrical Engineer and Proprietor Thresher Electric Co., Dayton, O.	A April 22, 1896 M June 24, 1898
THURNAUER, ERNST	Manager, Thomson-Houston International Elec. Co., 27 Rue de Londres, Paris, France.	A Oct. 14, 1887 M Dec. 6, 1887
TISCHENDOERFER, F. W.	Chief Electrical Engineer, Union Elektricitats Gesellschaft, Berlin, Germany.	A April 19, 1892 M Nov. 21, 1894
TRAFFORD, EDWARD W,	Electrical Engineer, Richmond Railway and Electric Co., Foot of 7th St., Richmond, Va.	A Feb. 21, 1894 M Dec. 19, 1894
UEBELACKER, CHAS. F.	General Manager, The Elmira Municipal Improvement Co., Elmira, N. Y.	A Feb. 7, 1890 M Nov. 15, 1893
UHLENHAUT; FRITZ, JR.	Whitestone, L. I.	A May 7, 1889 M Dec. 19, 1894
UPTON, FRANCIS R	Edison Laboratory; residence, 20 High St., Orange, N. J.	A May 17, 1887 M Mar. 15, 1892
VANSIZE, WILLIAM B. [Life Member.]	Solicitor of Patents, Expert in Patent Cases, 253 Broadway, New York City; residence, 210 Lincoln Road, Flatbush, Brooklyn, N. Y.	A April 15, 1884 M Oct, 21, 1884
VAN TRUMP, C. REGINALD	Engineer and Manager, Wilmington City Electric Co., Wilmington, Del.	A Feb. 5, 1886 M Feb. 21, 1894
VARLEY, RICHARD JR.	President, the Varley Duplex Magnet Co., 138 7th Street, Jersey City; residence, Phillipsdale, R.I.	A April 25, 1900 M Feb. 28, 1901
WADDELL, MONTGOMERY	Consulting Engineer, 72 Trinity Place, New York City.	A Feb. 7, 1888 M May 1, 1888

Name.	Address.	Date of Membership
WAIT, HENRY H.	Assistant Electrical Engineer, Western Electric Co., residence, 4919 Madison Ave., Chicago, Ill.	A Sept. 20, 1893 M June 20, 1894
WALDO, LEONARD	Electrical Engineer, Room 1514, 71 Broadway, New York; residence, 520 Stelle Ave., Plainfield, N. J.	A June 5, 1888 M Dec. 4, 1888
WALKER, SYDNEY F.	Consulting Electrical Engineer, 2 Kensington Gardens Square, London W., Eng.	A June 2, 1885 M May 17, 1887
WALL, LOUIS JAMES BENARD	Full Partner, Splatt, Wall & Co., Perth, Western Australia.	A July 26, 1900 M Nov. 23, 1900
WARING, JOHN	31 Russ St., Hartford, Conn.	A Dec. 16, 1890 M April 17, 1895
WARNER, ERNEST P.	Electrical Engineer, Western Electric Co.; residence, 402 Belden Ave., Chicago, Ill.	A Sept. 20, 1893 M June 20, 1894
WATERMAN, F. N.	Mechanical and Electrical Engineer, 150 Nassau St., New York City.	A Feb. 21, 1893 M June 20, 1894
WEAVER, W. D.	(*Manager.*) Editor *Electrical World and Engineer*; residence, Englewood, N. J.	A May 17, 1887 M May 17, 1887
WEBB, HERBERT LAWS	18 Cortlandt St.; residence, 253 West 42d St., New York City.	A Oct. 21, 1890 M Dec. 16, 1890
WEEKS, EDWIN R.	Consulting Electrical Engineer, 608 New Nelson Bldg., Kansas City, Mo.	A Sept. 6, 1887 M Nov. 1, 1887
WELLER, HARRY W.	Electrical Engineer, 202 St. James St., Montreal, P. Q.	A Oct. 21, 1890 M Nov. 24, 1891
WESTON, EDWARD	(*Past President.*) Vice-President, Weston Electrical Instrument Co., 120 William St., and 645 High St., Newark, N. J.	A April 15, 1884 M Oct. 21, 1884
WETZLER, JOSEPH	President, The Electrical Engineer Institute of Correspondence Instruction, 240 W. 23d St.; residence, 257 W. 104th St., N.Y. City.	A April 15, 1884 M Dec. 9, 1884
WHARTON, CHAS. J.	Palace Chambers, Westminster, London, Eng.	A Jan. 3, 1888 M May 1, 1888
WHEELER, SCHUYLER SKAATS, *Sc.D.* [Life Member.]	President, Crocker-Wheeler Co., 39 Cortlandt St., N. Y., and Ampere, N. J.; residence, 4 West 33d St., New York City.	A June 2, 1885 M Sept. 1, 1885
WHITE, JAMES GILBERT	J. G. White & Co., Electrical Engineers and Contractors, 29 Broadway, New York City.	A April 2, 1889 M May 15, 1900
WHITE, WILL F.	Electrical Engineer, General Manager The Cincinnati Edison Electric Co., 220 W. 8th St., Cincin. O.	A Feb. 7, 1890 M July 27, 1898
WHITE-FRASER, GEO.	*Mem. Can Soc. C. E.*; 18 Imperial Loan Building, Toronto, Ont.	A Sept. 22, 1891 M Dec. 18, 1895

Name.	Address.	Date of Membership.
Wiener, Alfred E.	Chief Instructor, The Electrical Engineer Institute, 240 W. 23d St., NewYork.	A May 16, 1893 M May 15, 1894
Wilcox, Norman T.	Sup't Colorado Electric Power Co., Cañon City, Col.	A May 21, 1895 M Jan. 22, 1896
Willis, Edward J.	President, Richmond Electric Co., 211 E Franklin St., Richmond, Va.	A Nov. 30, 1897 M Feb. 28, 1900
Willyoung, Elmer G.	E. G. Willyoung & Co., Electrical and Scientific Instruments, 11 Frankfort St., New York City..	A Nov. 24, 1891 M Dec. 20, 1893
Wilson, Charles H.	General Manager, Southern Bell Telephone and Telegraph Co., 26 Cortlandt St., New York City.	A Nov. 24, 1891 M Feb. 16, 1892
Wilson, Fremont	Consulting Engineer, 66 Maiden Lane (Telephone, 1651 Cortlandt) New York City: residence, 10 Hamilton Ave., Yonkers, N. Y.	A Mar. 6, 1888 M June 5, 1888
Wilson, Harry C.	Supt. of P. O. Telegraph with the Government, Kingston, Jamaica, West Indies.	A Jan. 19, 1891 M June 7, 1892
Winchester, A. E.	Electrical Commissioner and General Supt., City of South Norwalk Electric Works, also Consulting Engineer for Municipalities: residence, 4 Gerard Place, South Norwalk, Conn.	A June 8, 1887 M Nov. 1, 1887
Winslow, George Herbert	Consulting Electrical Engineer, 339 Fifth Ave., Pittsburg, Pa.	A April 17, 1895 M Feb. 26, 1896
Wolcott, Townsend	Electrician; residence, 329 Clinton St., Brooklyn, N. Y.	A Mar. 6, 1888 M Dec. 16, 1890
Wolverton, B. C.	Engineer, N. Y. & Pa. Telephone and Telegraph Co., Elmira, N. Y.	A Mar. 18, 1890 M Feb. 21, 1895
Wordingham, Chas. H.	City Electrical Engineer, The Manchester Corporation Electric Light Station, 19 Brasenose St., Manchester, England.	A July 27, 1898 M Oct, 26, 1898
Wotton, James A.	Manager Wotton Electric and M'f'g. Co. Box 543, Atlanta, Ga.	A Oct. 27, 1897 M Feb. 28, 1901
Wright, Peter	President, Virginia Electric Company, Norfolk, Va.	A May 16, 1889 M Jan. 16, 1895
Wurts, Alexander Jay	Westinghouse Electric & Mfg. Co., Allegheny, Pa.	A April 19, 1892 M Nov. 15, 1892
Young, C. Griffith	Engineer Construction, J. G. White & Co., 29 Broadway, New York.	A Jan. 3, 1889 M April 21, 1891
Young, Walter Douglas	Electrical Engineer B. & O. R. R., Roland Park, Baltimore, Md.	A Apr. 26, 1899 M Jan. 24, 1900

(17)

Members, ... 387

Name.	Address.	Date of Election.
Balsley, Abe	Electrician, Terre Haute Electric Co., No. 118 9th Street, Terre Haute, Ind.	Oct. 27, 1897
Bancroft, Chas. F.	Electrical Engineer, Massachussetts Electric Companies, 14 Kilby St., Boston, Mass.	Dec. 18, 1895
Bangs, Chas. R.	Special Agent, American Telephone and Telegraph Co., 15 Dey St., New York.	Jan. 26, 1898
Banks, William C.	Electrician, Gordon Battery Co., New York City.	May 18, 1897
Barnes, Chas. R.	City Electrician and Electrical Expert to State R. R. Commission, Rochester, N. Y.	Aug. 13, 1897
Barnes, Edward A.	Electrical Expert, Fort Wayne Electric Co., Fort Wayne, Ind.	Sept. 20, 1893
Barnes, Howell Henry	General Engineer, Mexican Electric Works Ltd. Apartado, 905, Mexico City.	Feb. 28, 1900
Barnett, Carl P.	Draftsman and Engineer, with S. & S. Packing Co., 41st St. and Ashland Ave., Chicago.	Jan. 25, 1901
Baron, Max D.	Outside Superintendent for Harry Alexander; residence, 61 East 75th St., New York City.	Mar. 28, 1900
Barr, Frank Adelbut	Manager and Electrician, Fries M'f'g. and Power Co., Winston-Salem, N. C.	Jan. 9, 1901
Barr, John B.	Electrical Engineer, General Electric Co., Schenectady, N. Y.; residence, 234 Union Street.	April 25, 1900
Barry, David	Electrician and Superintendent, Amherst Gas Co., Amherst, Mass.	Aug. 5, 1896
Barton, Enos M.	President Western Electric Co., Clinton and Congress Sts., Chicago, Ill.	July 12, 1887
Barton, Philip Price	Assistant Superintendent, The Niagara Falls Power Co., Niagara Falls, N. Y.	July 12, 1900
Bates, Frederick C.	Electrical Engineer, General Electric Co., 44 Broad St., New York City.	Jan. 20, 1891
Bates, Putnam A.	Assistant Secretary, Crocker-Wheeler Co., 39 Cortlandt St.; residence, 113 W. 72d St., New York City.	Jan. 20, 1897
Baugher, E. C.	Resident Engineer, Westinghouse Elec. & M'f'g Co., c/o Tokata & Co., Tokio, Japan.	Nov. 22, 1899
Baum, Frank George	Stanford University, Cal	Nov. 22, 1899
Bayley, Guy Lynfield	Assistant Manager Engineering Department, The American Trading Co., No. 28 Yokohama, Japan.	Feb. 28, 1901
Beaumont, Chas. W.	Assistant with Frank B. Rae, 45 Broadway; residence, 275 W. 127th St., New York City.	Jan. 9, 1901

Name.	Address.	Date of Election
BEEBE, MURRAY C.	Geo. Westinghouse, Exp. Dept., Westinghouse E. and Mfg. Co., Amber Club, Pittsburg Pa.	Jan. 26, 1898
BEHREND, BERNHARD A.	In charge Alternating Current Department, Bullock Electric Mfg. Co. Norwood, O.	Jan. 24, 1900
BELL, ORA A.	Electrical Engineer, Western Electric Co., 463 West St., New York; residence, 352 West 117th Street, New York.	Aug. 5, 1896
BELLMAN, JOHN JACOB	Electrical Engineer, Westinghouse, Church, Kerr & Co., 26 Cortlandt St.; residence, 90 King St., New York, N. Y.	Dec. 28, 1898
BENNETT, EDWIN H., JR.	Electrician and Engineer, Diehl & Co., Elizabethport, N. J., and 19 West 33d St., Bayonne, N. J.	June 20, 1894
BENNETT, JOHN C.	Electrician, General Electric Co., 44 Broad St. New York City.	Mar. 18, 1890
BENOLIEL, SOL. D., *B. S.*, *E. E.*, *A. M.*	Consulting Electrical Engineer, Adelphi College, Brooklyn, N. Y.	Oct. 21, 1896
BENTLEY, MERTON H.	Superintendent, New Telephone Co., 221 N. Scoville Ave., Oak Park, Ill.	Oct. 18, 1893
BERG, ERNST JULIUS	Engineer, General Electric Co.; residence, 243 Liberty St., Schenectady, N. Y.	Sept. 19, 1894
BERG, ESKIL	Electrical Engineer, Gen'l Electric Co., Schenectady, N. Y.	Nov. 20, 1895
BERGENTHAL, VICTOR W.	The Stanley Electric M'f'g. Co.; residence, 74 Wendell Ave., Pittsfield, Mass.	Jan. 9, 1901
BERLINER, EMILE	Inventor, Columbia Road, between Fourteenth and Fifteenth Sts., Washington, D. C.	April 15, 1884
BERRESFORD, ARTHUR W., *B.S.*, *M.E.*	Supt., The Cutler-Hammer M'f'g. Co., 12th St. and St. Paul Ave., Milwaukee, Wis.	May 15, 1894
BEST, A. T.	Electrical Engineer, 703 Showers Ave., Harrisburg, Pa.	April 19, 1894
BETHELL, U. N.	General Manager, The New York Telephone Co., 15 Dey St., New York City.	Jan. 17, 1894
BETTS, HOBART D., *E. E.*,	Room 517, 141 Broadway, New York, N. Y.; residence, Englewood, N. J.	Aug. 5, 1896
BEVERIDGE, EDMUND WALTER	Assistant Engineer, P. W. D. Bunno via Sujawal, Karachi D. Sind. India.	Jan. 24, 1900
BIDDLE, JAMES G.	Electrical and Scientific Instruments, Stephen Girard Bldg., Philadelphia, Pa.; residence, 417 West Price St., Germantown, Pa.	Aug. 5, 1896
BIJUR, JOSEPH, *A. B.*, *E. E.* [Life Member]	210 Centre, St., Telephone, 3276 "Spring;" residence, 310 West 80th St., New York City.	May 15, 1894

Name.	Address.	Date of Election.
Black, Chas N.	Ford, Bacon & Davis, 149 Broadway, New York; residence, 31 Boyken St., Morristown, N. J.	April 19, 1890
Black, Howard D.	With Blackall & Baldwin, 39 Cortlandt St.; house, 340 Manhattan Ave., New York, N. Y.	Sept. 15, 1897
Blackall, Frederick, S.	P. O. Box, 267; office, 39 Cortlandt St.; residence, 51 Manhattan Ave., New York.	Sept. 15, 1897
Blackwell, Francis O.	Engineer, Power and Mining Dept., General Electric Company, Schenectady, N. Y.	Mar. 28, 1900
Blake, Henry W.	Editor, *Street Railway Journal*, 120 Liberty St., New York City.	Nov. 13, 1888
Blake, Theodore W.	Electrical Engineer, 410 Bleecker St., residence, Engineers Club, 374 5th Ave., New York, N. Y.	Sept. 20, 1893
Blakemore, Maurice Neville	Electrical Engineer, with Westinghouse E. & M. Co., Pittsburg; residence, 306 The Colonial Bldg., Wilkinsburg, Pa.	Jan. 25, 1901
Blanchard, Charles M.	Union League, Philadelphia, Pa.	Sept. 19, 1894
Bliss, Louis Denton	Principal Bliss Electrical School, 614 12th Street, Washington, D. C.	July 12, 1900
Bliss, William L., *B. S.*, *M. M. E.*	Electrical Engineer, 128 Front St., New York City; residence, 505 Throop Ave., Brooklyn, N. Y.	Mar. 21, 1894
Blizard, Charles	Manager Sales Department Electric Storage Battery Co., 19th St., and Allegheny Ave., Philadelphia; residence, 409 West Price St., Germantown, Pa.	Nov. 21, 1894
Blunt, Willam W.	Engineer, Westinghouse Electric and M'f'g Co., Ltd., Westinghouse B'ld'g, Norfolk St., Strand, W. C., London, Eng.	Dec. 16, 1896
Bogen, Louis E.	Instructor in Physics, University of Cincinnati; residence, 547 Hale Ave., Avondale, Cincinnati O.	May 16, 1899
Bogue, Charles J.	Manufacturer and Dealer in Electrical Supplies, 206 Centre St., N.Y. City.	Dec. 3. 1889
Bohm, Ludwig K., *Ph.D.*	Consulting Electrical and Chemical Expert, 320 Broadway, N. Y. City.	Nov. 15, 1892
Bolan, Thomas V.	Local Engineer, General Electric Co., 214 S. 11th St.; residence, 708 N. 40th St., Philadelphia, Pa.	Aug. 5, 1896
Bonynge, Paul	Attorney and Counsellor-at-Law firm of Latson & Bonynge, 141 Broadway, New York, residence, 261 Quincy Street, Brooklyn, N. Y.	May 16, 1899
Bowie, Augustus Jesse, Jr.	Draughtsman, Bakersfield, Cal.	May 15, 1900
Bowman, Joseph H.	Care Interoceanic Railway Co., San Lazero Station, City of Mexico, Mexico.	May 16, 1899

Name.	Address.	Date of Election
Boyd, John Duncan	Electrician, Yuba Electric Power Co., Marysville, Cala.	Feb. 28, 1900
Boyles, Thomas D.	Electrical Engineer, General Electric Co.; residence, 406 Union St., Schenectady, N. Y.	Mar. 20, 1895
Brackett, Byron B.	With Rowland Telegraphic Co., 916 McCulloh St., Baltimore, Md.	Nov. 30, 1897
Brackett, Prof. Cyrus F.	Princeton, N. J.	April 15, 1889
Braddell, Alfred E.	Electrical Inspector, Underwriters' Association, Middle Department, 316 Walnut St., residence. 7435 Boyer St., Mt. Airy, Philadelphia, Pa.	Sept. 1, 1890
Brady, Paul T.	Manager, Central N. Y. Agency, Westinghouse Electric and Mfg. Co., Syracuse, N. Y.	July 12, 1887
Bragg, Charles A.	Manager Phila. Agency, Westinghouse Electric and Mfg. Co., 708 Land Title Building, residence, 3420 Powelton, Ave., Philadelphia, Pa.	Sept. 20, 1893
Brayshaw, I.	Telegraph Inspector Great Southern Railway, City of Buenos Aires.	Aug. 5, 1896
Brewster, Walter Scott	Electrician, Standard Underground Cable Co., 26 Washington St., Perth Ambcy, N. J.	Apr. 26, 1901
Brixey, W. R.	Proprietor and Manufacturer, Day's Kerite Wire and Cables, 203 Broadway, New York City.	Sept. 20, 1893
Broich, Joseph	Superintendent and Electrician, with F. Pearce, New York City; residence, 1622 8th Ave., Brooklyn, N.Y.	Jan. 17, 1894
Broili Frank	Electrical Engineer, California Elec. Works ;residence, 154 Hickory Ave., San Francisco, Cal.	Feb. 23, 1898
Brophy, William	17 Egleston St., Jamaica Plain, Mass	Mar. 5, 1889
Browd, Paul K.	Chief Engineer, The Russian Electric Company, "Union." Box 188, Kiev., Russia.	Feb. 15, 1899
Brown, Chas. L.	Gen'l Manager and Sec'y, Chicago Mutoscope Co., 1211 Monadnock Block, Chicago, Ill.	Nov. 20, 1895
Brown, Ellis Eugene	Electrical Engineer, Philadelphia and Reading Railway Co., 7th and Franklin Streets, Reading, Pa.	May 16, 1899
Brown, Hugh Thomas	Mechanical and Electrical Engineer, with General Electric Co., Box 47, Richmond, Va.	Jan. 26, 1898
Brown, Warren Day	Electrical Engineer, The Auto-Electric Co., 61 Elm St.; residence, 103 E. 39th St , New York City.	Jan. 25, 1901
Browne, Wm. Hand, Jr.	Asst. Professor of Electrical Engineering, The University of Illinois, Urbana, Ill.	April 25, 1900

Name.	Address.	Date of Election.
Bryan, Richard R.	Consulting and Contracting Mechanical and Electrical Engineer, 1018 Prudential Building, Atlanta, Ga.	May 15, 1900
Buckingham, Chas. L.	Patent Attorney, Western Union Telegraph Co., 195 Broadway, P. O. Box 856, New York City.	April 15, 1884
Bull, Robert Wilson	Electrical Engineer, The New Jersey Zinc Co., (of Penn.,) Palmerton, Pa.	Mar. 22, 1901
Bunce, Theodore D.	President, The Storage Battery Supply Co., 239 E. 27th St., New York City.	May 20, 1890
Burdick, Irving Edward,	Treasurer and Engineer, Naval Electric Co., 95 Liberty St ; residence, 146 West 104 St., New York.	Oct. 24, 1900
Burke, James	Klopstack Strasse, 15; Berlin, Germany.	May 16, 1893
Burkett, Chas. Watson	General Inspector, Southern Bell Tel. & Tel. Co., Atlanta, Ga.	Aug. 23, 1899
Burnett, Douglass, *B.S.*	Edison Illuminating Co., Inspection Dept., 55 Duane St., New York City; residence, 42 Livingston St., Brooklyn, N. Y.	Feb. 21, 1893
Burnett, James Aubrey	Draftsman and Designer, Royal Electric Co., 94 Queen St.; residence, 19 Shuter Street. Montreal	Apr. 26, 1901
Burroughs, Harris S.	Electrical and Mechanical Engineer, Ballanytne & Evans, 20 Nassau St., New York; residence, 1416 Pacific St., Brooklyn, N. Y,	Nov. 30. 1897
Burt, Byron T.	Supt. Chattanooga Light & Power Co., Chattanooga, Tenn.	Sept. 25, 1895
Burton, Paul G.	Switchboard Dep't. Western Electric Co.; residence, 475 Central Park, West, New York City.	Nov. 20, 1895
Butler, William C.	President, The Puget Sound Reduction Co., Everett, Washington.	Mar. 21, 1893
Buys, Albert	Electrical Engineer, The Rahway Electric Co., Pitman.Grove, N. J.	Feb. 7, 1890
Byrns, Robert A.	Sales Manager. Metropolitan District, United Telpherage Co., 20 Broad Street. New York City.	Dec. 16. 1896
Cabot, Francis Elliott	Supt. of Inspection and Electrician, Boston Board of Fire Underwriters, 55 Kilby Street Boston ; residence, East Milton, Mass.	April 17, 1895
Caldwell, Edward	President Trade Paper Advertising Co., 150 Nassau St., New York City; residence, 50 Westervelt Ave., Plainfield, N. J.	Jan. 20, 1891
Caldwell, Francis Cary	Professor of Electrical Engineering, Ohio State University, residence, 401 W. 6th Ave., Columbus, O.	June 20, 1894
Campbell, Henry Arthur	Electrician, Jamaica Electric Light & Power Co., Ltd., 38 Harbor St , Kingston, Jamaica.	Sep. 27, 1899
Canfield, Milton C.	Electrical Engineer, 48 Greymont St., Cleveland, O.	Feb. 21, 1893

Name.	Address.	Date of Election.
CANFIELD, MYRON E.	Western Electric Co.; residence, 404 W. 44th St. New York City.	May 21, 1895
CAPUCCIO, MARIO	Raimondo & Capuccio, Consulting Engineers and Patent Agents, Piazza Statuto 15, Turin, Italy.	Dec. 20, 1893
CARNAGHAN, E. D.	In charge of machinery with Cipriano Guerrero. Durango, Do. Mexico.	July 26, 1900
CARPENTER, CHAS. E.	Vice-President, Carpenter Enamel Rheostat Co., Bronxville, N. Y.	Aug. 5, 1896
CARTER, FREDERICK WILLIAM *M. A.*,	With General Electric Co., Schenectady, N. Y	Sept. 28, 1898
CARTY, JOHN J.	(*Manager.*) Chief Engineer, New York Telephone Co., 15 Dey St., New York City; residence, Short Hills, N. J.	April 15, 1890
CASE, WILLARD E.	196 West Genesee St., Auburn, N. Y.	Feb. 7, 1888
CASSIDY, JOHN	Superintendent Mutual Telephone Co., Honolulu, Hawaiian Islands, U.S.A.	Nov. 23, 1898
CHAPMAN, A. WRIGHT	160 Hicks St., Brooklyn, N. Y.	Mar. 25, 1896
CHAPPELL, WALTER E. [Life Member.]	Electrician, on U. S. S. Chicago, U. S. Navy, Washington, D.C.; residence, Barnesville, O.	May 16, 1899
CHENEY, FREDERICK A.	Box 188, St. Catharines, Ont.	Oct. 1, 1889
CHILD, CHARLES TRIPLER	Technical Editor, *Electrical Review*, New York City.	Jan. 25, 1901
CHILDS, SUMNER W.	New York City.	May 15, 1894
CLARK, CHAS. M., *E. E.*,	Clark & MacMullen, 42 E. 23d St., New York City.	April 22, 1896
CLARK, FARLEY GRANGER	Electrician in charge 96th St. Power Station, Metropolitan St. Ry. Co., 96th St. and 1st Ave.; residence, 454 Manhattan Ave., New York City.	Apr. 26, 1901
CLARK, LEROY, JR.	Electrical Engineer of the Safety Insulated Wire and Cable Co., 229 West 28th St., residence, 208 West 85th St., New York City.	May 15, 1894
CLARK, WILLIAM J.	General Manager, Foreign Dept. General Electric Co., 44 Broad Street, New York City.	April 22, 1896
CLARK, WM. EDWIN	Partner Clark & Mills, Engineers and Contractors, 543 Boylston St., Boston and 1400 Mass. Ave., Cambridge; residence, 57 Brattle St., Cambridge, Mass.	Aug. 23, 1899
CLEMENT, EDWARD E.	Patent Attorney and Electrical expert, Firm of Clement & Gharky, 1205-6 Stephen Girard B'ld'g., Phila., Pa.	May 18, 1897
CLEMENT, LEWIS M.	Haywards Almeda Co., Cal.	April 21, 1891
CLOUGH, ALBERT L.	Box 114, Manchester, N. H.	Feb. 21, 1894
CODMAN, JOHN STURGIS,	Consulting Engineer. Associated with R. S. Hale, 31 Milk St.; residence, 57 Marlborough St., Boston, Mass.	Feb. 15, 1899
CODY, L. P.	Manager and Engineer, Grand Rapids Electric Co., 9 South Division St., Grand Rapids. Mich.	Aug. 5, 1896
COFFIN, CHAS. A.	General Electric Co., 180 Summer St., Boston, Mass.	Dec. 6, 1887

Name.	Address.	Date of Election.
Coho, Herbert B.	New York Manager Eddy Elec. Mfg. Co., 149 Broadway, New York City, residence, Mt. Vernon, N. Y.	Mar. 21, 1894
Cole, Wm. Howard	Engineer, Carris de Ferro de Lisbon, Santo Auraro, Lisbon, Portugal.	April 25, 1900
Coleman, Walter H.	Supt. and Treasurer, Andover Electric Co., Andover, Mass.	Sept. 28, 1898
Coles, Edmund P.	Local Engineer, General Electric Co., 214 S. 11th St., Philadelphia, Pa.	Oct. 23, 1895
Collett, Samuel D.	Eastern Manager, Elevator Supply and Repair Co., 136 Liberty St., New York City; residence, 156 Clinton St,, Brooklyn, N. Y.	Feb. 26, 1896
Compton, Alfred G.	Professor of Applied Mathematics, College of the City of New York, 17 Lexington Ave.; residence, 40 W. 126th St, New York City.	Nov. 1 1887
Converse, V. G.	President and General Manager of the Converse Transformer Co., 15th St. and Liberty Ave., Pittsburg, Pa.	Nov. 23, 1900
Cook, Edward Jerome	Electrical Engineer, Cleveland Electric Railway Co., 06 Commonwealth Ave., Cleveland, O.	May 15, 1900
Cooke, George A.	Electrical Engineer and Supt., Hawaiian Electric Co., Honolulu, H. I. residence, Chicago, Ill.	Mar. 22, 1901
Copeland, Clement A.	Acting Professor of Electrical Engineering, Stanford University, Cal.	June 23, 1897
Corey, Fred Brainard	Engineer, General Electric Co.; residence 3 High St., Schenectady, N. Y.	Dec. 20, 1893
Cornell, John B.	Niles-Bement Pond Co., 136 Liberty St., New York City.	Sept. 25, 1895
Corson, William R. C.	Superintendent, The Eddy Electric Mfg. Co., Windsor, Conn.	Jan. 17, 1893
Cory, Clarence L.	Professor of Electrical Engineering, University of California, Berkeley, Cal.	April 19, 1892
Cosgrove, James Francis	38 St. Andrews Place, Yonkers, N.Y.	Nov. 23, 1898
Crain, John Jay,	329 49th St., Newport News, Va.	Dec. 16, 1896
Crandall, Chester D.	Assistant Treasurer, Western Electric Co., 259 South Clinton St.; residence, 2821 Sheridan Road Chicago, Ill.	Sept. 27, 1892
Crane, W. F. D.	Electrical and Mechanical Engineer, United Telpherage Co., 20 Broad St., New York; residence, 24 Reynolds Terrace, Orange, N. J.	Feb. 7, 1888
Crawford, David Francis	Supt. Motive Power, Penn'a Co., Fort Wayne, Ind.	Sept. 25, 1895
Creaghead, Thomas J.	President and General Manager, Creaghead Engineering Co., 802 Plum St., Cincinnati, O.	Sept. 20, 1893

Name.	Address.	Date of Election
Crehore, Albert C., *Ph.D.*	The Crehore-Squier Intelligence Transmission Co., Brookside Park, Tarrytown, N. Y.	Dec. 21, 1892
Criggal, John E.	Mechanician with Western Electric Co.; residence, 296 W. 11th St., New York City.	June 20, 1894
Crocker, Eben Clinch	Electrical Engineer, American Ordnance Co., 29 Harriet Street, Bridgeport, Conn.	Jan. 26, 1898
Crosby, Oscar T.	Potomac Light and Power Co., 1417 G Street, Washington, D. C.	Mar. 18, 1890
Crowell, Robinson	Assistant Electrician, Sacramento Electric Gas and Railway Co,,Sacramento, Cal.	Dec. 28, 1898
Crozier, Arthur Bertram	Draughtsman and Engineer, Schwarzchild & Sulzberger Packing Co.. 41st St. and Ashland Ave., Chicago, Ill.	Jan. 9, 1901
Cumner, Arthur B.	251 So. 12th St., Philadelphia, Pa.	Feb. 27, 1895
Cunningham, E. R.	Sup't Fort Dodge Light and Power Co., Fort Dodge, Iowa.	Jan. 22, 1899
Cuntz, Johannes H.	325 Hudson St., Hoboken, N. J.	Mar. 5, 1889
Currie, N. M.	Santiago, Chili.	Feb. 15, 1899
daCunha, Manoel Ignacio	Manager of the Electrical Section, Emprera Industrial Gram-Para, Para, U. S. of Brazil.	May 16, 1893
Daggett, Royal Bradford	Electrical Engineer, Electric Storage Battery Co., 43 Nevada Block, San Francisco, Cal.	Jan. 25, 1899
Damon, Geo. A.	With B. J. Arnold, Electrical Engineer, 1541 Marquette Building, Chicago, Ill.	Jun. 24, 1898
Damon, Geo. B.	c/o A. S. M. E., 12 W. 31st St., New York City.	June 23, 1897
Danielson, Ernst	Consulting Electrician, Westeras, Sweden.	June 27, 1895
Dates, Henry B,,	Professor of Electrical Engineering and Physics, Clarkson School of Technology, Potsdam, N. Y.	Dec. 28, 1898
Davenport, George W.	183 Essex St., Boston, Mass.	June 4, 1889
Davidson, Edw. C.	Patent Lawyer, 141 Broadway, New York City.	Feb 7, 1890
Davis, Delamore L.	Superintendent, Salem Electric Light and Power Co., 299 Lincoln Ave., Salem, O.	April 2, 1889
Davis, Harry Phillips	Engineer of Detail Dept., Westinghouse E. & M. Co.; residence, 327 Neville St., Pittsburg, Pa.	Jan. 25, 1901
Davis, Leslie Foster	Secretary and Manager, Jamaica Electric Light & Power Co., Ltd. 38 Harbor St., Kingston, Jamaica	Sept. 27, 1899

Name.	Address.	Date of Election
Davis, Joseph P.	Engineer, American Bell Telephone Co., 113 W. 38th St., New York City.	April 15, 1884
Davis, Philip W.	Engineer of New England Office, The Electric Storage Battery Co., Boston; residence, 110 Irving Street, Cambridge, Mass.	May 15, 1900
Davis, W. J., Jr.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	Mar. 20, 1895
Dawson, Josiah	Contractor for Electric Light and Power, etc , Cuba Street Extension, Wellington, New Zealand.	Jan. 9, 1901
Deeds, Edward Andrew,	President Board of Engineers, The Natural Food Co.; residence, 527 Riverside, Niagara Falls, N. Y.	Nov. 23, 1900
Degen, Lewis	Address unknown.	Sept. 25, 1895
Dempster, Thomas	Electrical Engineer, General Electric Co., Schenectady, N. Y.	May 17, 1898
de Muralt, Carl L.	Electrical Engineer, Baden, Switzerland.	May 15, 1900
de Nordwall, Charles Flesch,	Manager of the Export Department, Allgemeine Elektricitats-Gesellschaft, 22 Schiffbauerdamm, Berlin, N. W. Germany.	Sept. 27, 1892
Denton, James E.	Professor of Experimental Mechanics, Stevens Institute of Technology, Hoboken, N. J.	July 12, 1887
de Chatelain, Mikail Andrejevitch	Prof. of Electrical Engineering, Mining Institution and Electro-Technical Institution, Wasily Ostrow, 10 line No. 5, St. Petersburg, Russia.	Nov. 23, 1900
DeRedon, Constant	Consulting Engineer. [Address unknown.]	May 18, 1897
de Waal, Wm. H.	Engineer, Accumulator Mfg. Co., Cadena, No. 3, Mexico City, Mexico.	April 25, 1900
Dickerson, E. N.	Attorney-at-Law, 141 Broadway; residence 64 E. 34th St., New York City.	April 15, 1884
Dieterich, Fred. G.	Solicitor of Patents and Mechanical Expert, 602 F Street, Washington, D. C.	July 18, 1899
Dinkey, Alva C.	Supt. Electric Dept., Homestead Steel Works, Munhall, Pa.	Feb. 17, 1897
Dobbie, Robert S.	Electrical Engineer, Riding Mill-on-Tyne, Northumberland, Eng.	Feb. 5, 1889
Doherty, Henry L.	40 Wall St., New York City.	Sept. 28, 1898
Doolittle, Clarence E.	Manager and Electrician. Roaring Fork Electric Light and Power Co., Aspen, Colo.	May 15, 1894

Name.	Address.	Date of Electron.
DOOLITTLE, THOMAS B.	Engineering Department, American Bell Telephone Co., 125 Milk St., Boston, Mass.	May 16, 1893
DOREMUS, CHARLES AVERY	*M.D. Ph.D.* 59 W. 51st St., New York City.	July 7, 1884
DOUBT, THOMAS EATON	Professor of Physics and Electrical Engineering, The University of Washington, Seattle, Wash.	Jan. 9, 1901
DOWIE, HORACE	Engineering Staff, Crocker-Wheeler Co., Ampere, N. J.	Jan. 25, 1901
DOWNES, LOUIS, W.	Vice-President and General Manager, The D. & W. Fuse Co., 407 Pine St., Providence, R. I.	Nov. 22, 1899
DOWNING, P. M.	Electrician, Standard Mining Co., Bodie, Mono Co., Cal.	June 24, 1898
DRESSLER, CHARLES E.	17 Lexington Ave., New York City.	Dec 16, 1890
DRYSDALE, DR., W. A.	Consulting Electrical Engineer, 414 Hale Building, Philadelphia, Pa.	Sept. 19, 1894
DUBOIS, TUTHILL,	Electrical Contractor, 19 Park Place; residence, 209 Schenck Ave., Brooklyn, N. Y.	Aug. 23, 1899
DUNCAN, JOHN D. E. [Life Member.]	Engineer. with Sanderson and Porter, 31 Nassau St., New York City.	Mar. 20, 1895
DUNCAN, THOMAS	Manager, Meter Dep't, Siemens & Halske Electric Co., Grant Works, Chicago; residence, 410 North Central Ave., Austin, Ill.	Oct. 17, 1894
DUNN, CLIFFORD E.	Patent Attorney, 1029 Park Row Bldg, New York City, residence, 12-a Monroe St., Brooklyn, N. Y.	Feb. 15, 1899
DUNN, KINGSLEY G.	General Supt. British Columbia Electric Railway L't'd., Vancouver, B. C.	Oct. 17, 1894
DURANT, EDWARD	Chief Electrical Engineer, Manhattan State Hospital of the State of New York, Ward's Island, N. Y.; residence, 115 East 26th St., New York City.	Nov. 15, 1892
DURANT, GEO. F.	General Manager Bell Telephone Co., of Mo., Telephone Building, St. Louis, Mo.	April 15, 1884
DYER, ERNEST I.	Engineer and Manager of the Engineering Department of the American Trading Co., Box 28, Yokohama, Japan.	Jan. 25, 1899
DYER, SHUBAEL ALLEN	Manager Supply Dept. Mexican General Electric Co., Box 403, Mexico City, Mexico.	May 15, 1900
DYSTERUD, EMIL	Superintendent and General Manager, Electric Light & Power Co., Monterey, Nuevo Leon, Mexico.	July 26, 1900
EDDY, H. C.	Electrical Engineer, Lees Building, Chicago, Ill.	June 20, 1894

Name.	Address.	Date of Election.
Edmands, I. R.	Electrical Engineer, Union Carbide Co., residence, 315 Buffalo Ave., Niagara Falls, N. Y.	June 23, 1897
Edmands, Samuel Sumner	Assistant in Electrical Engineering, Ohio State University, Columbus, O.	Mar. 22, 1901
Edwards, James P.	Consulting Electrician, Augusta, residence, Montesano, Summerville, Ga.	April 19, 1892
Edwards, Clifton V.	Attorney-at-Law and Solicitor of Patents, 220 Broadway, New York.	Nov. 22, 1899
Eglin, James Meikle	Chief of Electric Dept. Edison Electric Light Co., of Philadelphia, 10th and Sansom Sts.; residence, 4230 Chester Ave., Philadelphia, Pa.	July 26, 1900
Eglin, Wm. C. L.	Electrical Engineer, N. E. cor 10th and Sansom Sts., residence, 4230 Chester Ave., Philadelphia, Pa.	Sept. 19, 1894
Ekstrom, Axel	Electrical Engineer, General Electric Co.; Schenectady. N. Y.	June 17, 1890
Ellard, John W.	General Manager, United Electric Light and Power Co.,506 Merchants Bank Bldg, Baltimore, Md.	June 23, 1897
Elias, Albert B.	1310 Washburn Street, Scranton, Pa.	Jan. 26, 1898
Ellis, John	Manager, The Lonsdale Co 's Electric Light Plant, Lonsdale, R. I.	Apr. 26, 1899
Ellis, R. Laurie	Electrician, Seattle Electric Co., Seattle, Wash.	April 26, 1899
Elmer, William Jr.	Assistant Master Mechanic, Altoona Machine Shop, Altoona, Pa.	Mar. 18, 1890
Ely, Wm. Grosvenor, Jr.	Ass't Supt. Construction, General Electric Co., 849 Union Street, Schenectady, N. Y.	Mar. 21, 1893
Emerick, Louis W.	Electrical Engineer, 369 W. Monument Ave., Dayton, O.	Aug. 13, 1897
Entz, Justus Bulkley	Electrical Engineer, Electric Storage Battery Co., 19th St., and Allegheny Ave., Philadelphia, Pa.	Jan. 7, 1890
Erickson, F. Wm.	Electrical Engineer, The Erickson Electric Equipment Co., 71 Federal St., Boston, Mass.	Sep. 19, 1894
Esterline, J. Walter	Instructor Electrical Engineering, Purdue University, residence, 124 Grant St., Lafayette, Ind.	Mar. 28, 1900
Esty, William	Associate Professor of Electrical Engineering, University of Illinois, Urbana, Ill.	Mar. 20, 1895
Ethridge, Locke	Mechanical Engineer, 1001 Monadnock B'ld'g,44 E. 50th St.,Chicago, Ill.	Oct. 17, 1894
Evans, Clement W.	Electrical Engineer, American Engineering Co., Box 2100 Mexico City.	Feb. 28, 1900

Name.	Address.	Date of Election.
Evans, Paul H.	Chief Engineer Mexican General Electric Co., Apartado 403 Mexico City.	Jan. 24, 1900
Eyre, Manning K.	7 Union St., Schenectady, N. Y.	Oct. 17, 1894
Farnsworth, Arthur J.	Chief Engineer, East Chester Electric Co., 3 Depot Place, Mount Vernon; residence, 30 Beechwood Ave., New Rochelle, N. Y.	Jan. 16, 1895
Farrand, Dudley	General Manager, United Electric Company of New Jersey, 207 Market St.; residence, 141 Clinton Ave., Newark, N. J.	July 26, 1900
Fielding, Frank E. [Life Member.]	Chemist and Assayer, Virginia City, Nev.	Sept. 6, 1887
Finney, John C.	Asst. Secretary of the Wisconsin Trust Co., 1 and 3 Old Insurance Bldg.; residence, 34 Prospect Ave, Milwaukee, Wis.	Dec. 28, 1898
Firth, Wm. Edgar	Chief Engineer, The Midvale Steel Co., Nicetown, Philadelphia; residence, 7203 Boyer St., Germantown, Pa.	Mar. 25, 1896
Fish, Fred. Alan	Assistant Prof. of Electrical Engineering, Ohio State University, Columbus, O.	Mar. 28, 1900
Fitzhugh, Wm. H.	Supt. Bay City Electric Plant, Bay City, Mich.	April 27, 1898
Flather, John J.	Professor of Mechanical Engineering, University of Minnesota; residence, 316 10th Ave., S. E., Minneapolis, Minn	April 19, 1892
Fleming, John Breckenridge, *M. M.*,	and Elec. Engineer, Silver King Mill, Park City, Utah.	April 27, 1898
Fleming, John F.	Electrical Contractor, Brookline, Mass.	July 12, 1900
Fliess, Robert Anton	201 W. 55th St., New York City.	Mar. 23, 1898
Floy, Henry	Consulting Electrical and Mechanical Engineer, 220 Broadway, New York City.	May 17, 1892
Fog, Carl F.	Electrician, General Electric Co.; residence, Box 45, East Saugus, Mass.	Mar. 28, 1900
Foote, Thos. H.	Electrical Engineer, 173 Westfield Ave, Westfield, N. J.	April 21, 1891
Forbes, Francis	Lawyer, 32 Nassau St., New York City.	Sept. 16, 1890
Forbes, George	Electrical Engineer, 34 Great George St., London, Eng.	Feb. 21, 1894
Ford, Arthur Hillyer, *E. E.*	Instructor in Electrical Engineering, University of Colorado, Boulder, Col.	Mar. 24, 1897
Ford, Frank R., *M. E.*	Consulting Engineer, Ford, Bacon & Davis, 149 Broadway, New York City.	Mar. 25, 1896

Name.	Address.	Date of Election.
Ford, Wm. S.	Assistant to Chief Engineer, The American Bell Telephone Co., room 73, 125 Milk St. Boston, Mass.	June 7, 1892
Fowler, Geo. W.	Electrical Expert, The C. & C. Electric Co., Garwood, N. J.	Oct. 24, 1900
Francisco, M. J.	President and General Manager, Rutland Electric Light Co., Rutland, Vt.	June 17, 1890
Frank, Geo. William	With J. G. White & Co., 29 Broadway, New York City.	Sept. 28, 1898
Frankenfield, Budd	Instructor in Electrical Engineering, University of Wisconsin, 609 Lake St., Madison, Wis.	Feb. 17, 1897
Franklin, W. S.	Professor of Physics and Electrical Engineering, Lehigh University, South Bethlehem, Pa.	Jan. 22, 1896
Frantzen, Arthur	Electrical Engineer and Contractor, 225 Dearborn St., residence, 662 N. Irving Ave., Chicago, Ill.	Feb. 21, 1894
French, Thomas, Jr.	*Ph.D.* 713 E. Ridgeway Ave., Cincinnati, O.	Sept. 20, 1893
Friedlaender, Eugene	Electrician, Carnegie Steel Company, Duquesne, Pa.	Nov. 20, 1895
Fry, Donald Hume	The Standard Electric Co., Jackson, Amador Co., Cal.	Nov. 23, 1898
Gallaher, Edward B.	The Keystone Motor Co., Drexel Building; residence, 1230 Orkney St., Philadelphia, Pa.	Jan. 19, 1895
Gallatin, Albert R.	Student at Columbia University, residence 58 W. 55th St., New York City.	Mar. 23, 1898
Ganz, Albert F.	Assistant Professor, Physics and Applied Electricity. Stevens Institute; residence 612 River St., Hoboken, N. J.	April 26, 1899
Garfield, Alex. Stanley	Engineer, Cie Thomson-Houston, 27 Rue de Londres, Paris, France.	Jan. 26, 1898
Garrels, W. L.	Consulting Engineer, Franklin Bank B'ld'g.; residence, 4531 West Pine Boulevard, St. Louis, Mo.	Mar. 20, 1895
Gartley, Alonzo	General Manager, Hawaiian Electric Co., Honolulu, H. I.	July 12, 1900
Gaytes, Herbert	Electrical Engineer, Oakland, Cal.	Mar. 23, 1898
Gherardi, Bancroft, Jr.,	Chief Engineer, New York and New Jersey Telephone Co., 81 Willoughby St., Brooklyn; residence, 33 Evergreen Place, East Orange, N. J.	June 27, 1895
Gibson, Geo. H.	Assistant Editor Engineering News, 220 Broadway; residence 328 Lenox Ave., New York City.	Nov. 22, 1899
Gille, Henry John	Supt. Electric Dept., St. Paul Gas Light Co., St. Paul, Minn.	Jan. 25, 1901
Gilliland, E. T.	Pelham Manor, N. Y.	April 15, 1884
Gillis, Harry Alexander	General Superintendent, Richmond Locomotive Works, Richmond, Va.	Apr. 26, 1901

Name.	Address.	Date of Election.
Gladson, Wm. N.	Professor of Electrical Engineering, University of Arkansas, Fayetteville, Ark.	Dec. 28, 1898
Glass, Louis	Assistant General Manager, Pacific Telegraph and Telephone Co., Telephone Bldg., San Francisco., Cal.	Oct. 24, 1900
Goddard, Chris. M.	Secretary New England Insurance Exchange Sec'y Underwriters' National Electric Ass'n, 55 Kilby St,. Boston, residence. 11 Glenwood Ave., Newton Centre, Mass.	April 22, 1896
Goldmark, Chas. J.	Consulting Electrical Engineer, 66 New Street, Tel. 2729 Broad, New York City.	June 5, 1888
Gordon, Reginald	Instructor in Physics, Columbia University, residence, 315 W. 71st St., New York City.	Feb. 24, 1891
Gorrissen, Ch.	General Manager, The Rand Central Electric Works, Box 2671 Johannesburg, Transvaal.	Mar. 25, 1896
Gorton, Charles	Civil Engineer, Belmont, N. Y.	Nov. 12, 1889
Gotshall, Wm. C.	Electrical Vehicle Co., 46 Fifth Ave., New York.	Jan. 9, 1901
Gough, Harry Eugene	Assistant in Office Mechanical Engineers, Penn. R. R. Co., 1415 11th St., Altoona, Pa.	Jan. 9, 1901
Granbery, Julian H.	*Jun. Am. Soc. C. E.;* Asst. Engineer Manhattan Railway Co., 32 Park Place, New York; residence, 670 Penna Ave., Elizabeth, N. J.	Aug. 5, 1896
Grant, Louis T.	Vice-President and General Manager, Hawaiian Automobile Co., Box 536, Honolulu, H. I.	Nov. 22, 1899
Graves, Chas. B.	210 Washington St., Marblehead, Mass.	Sept. 15, 1897
Greenleaf, Lewis Stone	American Bell Telephone Co., 15 Oliver St., Boston, Mass.	Aug. 5, 1896
Green, Elwyn Clinton	With Commercial Electric Co.: residence, 1710 Prospect St., Indianapolis, Ind.	Mar. 25, 1896
Greenwood, Fred. A.	Secretary California Electric Works, 409 Market St., San Francisco, Cal.	April 28, 1897
Greenwood, George	Electrical Engineer and Superintendent, Jalapa Railway and Power Co., Jalapa, V. C., Mexico.	Jan. 24, 1900
Griffen, John D.	Inventor, Electric Conduit and Electric Signaling Apparatus, Broad-Exchange B'ld'g. 75 Broad St.; residence, 304 West 90th St., New York.	Aug. 13. 1897
Griffes, Eugene V.	c/o United Electric Co., Long Beach, Cal.	Feb. 26, 1896

Name.	Address.	Date of Election
GRIFFIN, CAP'T EUGENE	First Vice-President, General Electric Co., 44 Broad St., New York City.	Feb. 7, 1890
GROWER, GEORGE G.	Electrician and Chemist, Ansonia Brass and Copper Co., Ansonia, Conn.	Mar. 18, 1890
GUERRERO, JULIO	Associated with the Durango Electric Light Co., Victoria, 12 Durango, Mex.	April 25, 1900
GUTIERREZ, MANUEL R.	Professor of Physics, Normal School, Jalapa, V. C., Mexico.	Apr. 25, 1900
GUY, GEORGE HELI	Secretary, The New York Electrical Society, 120 Liberty St., New York City.	May 16, 1893
HAKONSON, CARL HAROLD	Electrical Engineer, Westend, Berlin, Germany.	Sept. 25, 1895
HALL, EDWARD J.	Vice-President and General Manager, American Telephone and Telegraph Co., 15 Dey St., New York City.	April 18, 1893
HALL, FRED'K A.	Engineer, The Johnson-Lundell Electric Traction Co., Ltd., 16 Soho Square, London, W.	Aug. 23, 1899
HALLBERG, J. HENRY	Electrician, General Incandescent Arc Light Co., 572 First Ave.; residence, 3 Beech Terrace, E. 143d St., New York City.	Aug. 23, 1899
HAMERSCHLAG, ARTHUR A.	Consulting Engineer, 41 Liberty St., New York City.	Mar. 25, 1896
HAMILTON, JAMES	Patent Law Specialist. 53 State St., Boston, residence, 205 Crafts St., Newtonville, Mass.	Nov. 23, 1898
HAMMATT, CLARENCE S.	Manager, Jacksonville Electric Light Co., Jacksonville, Fla.	Sept. 20, 1893
HANCOCK, L. M.	Supt., Nevada Division, Bay Counties Power Co., P. O. Box 151, Nevada City, Cal.	May 19, 1891
HANSCOM, WM. W.	Chief Electrical Engineer, Union Iron Works, 612 O'Farrell Street, San Francisco, Cala.	April 25, 1900
HANSON, ARTHUR JAMES	Lawrence & Hanson, 3 Wynyard St., residence, Drunnmoyne, Sydney, N. S. W.	Nov. 22, 1899
HARDING, H. McL.	20 Broad Street, New York City.	May 24, 1887
HARDY, CARL EARNEST	Laboratorian, Bureau of Construction and Repair, U. S. Navy Yard, Norfolk, Va.; residence, 216 London St., Portsmouth, Va.	Dec. 27, 1899
HARRIS, GEORGE H.	Electrical Engineer, Birmingham Railway and Electric Co., Birmingham, Ala.	June 20, 1894
HARTER, BRET	83 Wieting Block, Syracuse, N. Y.	July 26, 1900

Name.	Address.	Date of Election
Hartman, Herbert T.	2nd Vice-President and Chief Engineer, 1406 Land Title B'ld'g., residence, 3135 Clifford St., Philadelphia, Pa.	Mar. 21, 1893
Harvey, Robert R. [Life Member.]	10 So. Franklin St., Wilkes-Barre, Pa.	Sept. 25, 1895
Haskins, William Edgar	Chief Electrician, South Works, Am. Steel and Wire Co., 27 Whipple St., Worcester, Mass	Jan. 25, 1901
Hassler, Chas. T. F.	Electrical Engineer, "Union" Co., Riga, Russia.	Oct. 24, 1900
Hathaway, Joseph D., Jr.	Assistant in Cable Dep't Western Electric Co., 463 West St., N. Y. City.	Aug. 5, 1896
Hatzel, J. C.	Firm Hatzel and Buehler, 114 Fifth Ave., residence 1231 Madison Ave., New York City.	Sept. 3, 1889
Haubrich, Alex. Michael	Electrical Engineer, Central Union Telephone Co., 1309 Ashland Block, Chicago, Ill	Apr. 26, 1901
Healy, Louis W.	Treasurer, East Liverpool Railway Co., East Liverpool, Ohio.	June 26, 1891
Hedenberg, Wm. L.	Manager and Editor, *Electricity*, 136 Liberty Street, New York City.	Nov. 21, 1894
Heft, N. H.	Chief of Electrical Dep't N.Y.N.H. & H. R. R., New Haven; residence, Bridgeport, Conn.	Aug. 23, 1890
Heitmann, Edward, Jr.,	Stanley Electric M'f'g. Co., Pittsfield, Mass.	Oct. 24, 1900
Hellick, Chauncey Graham	Chicago Telephone Co., 203 Washington St., Chicago, Ill.	Jan. 26, 1898
Henderson, Alex.	Electrician, Sprague Electric Co., residence, 17 W. 106th St. N. Y.	Nov. 30, 1897
Henderson, Henry Banks	Riverside, Cal.	May 21, 1895
Henry, Geo. J., Jr.,	Engineer for The Pelton Water Wheel Co., 143 Liberty St. New York and 127 Main St., San Francisco, Cal.	April 27, 1898
Henry, Lewis Warner	Assistant in Engineering Department, Mexican General Electric Co, Mexico City.	Feb. 28, 1900
Herdt, Louis A.	Lecturer on Electrical Engineering, McGill University, Montreal, Canada.	May 16, 1899
Hermessen, John Louis	83 Cannon St., London, E. C., England.	Jan. 20, 1897
Hessenbruch, George S.	*E.E. Ph.D.* Ass't Engineer to Sup't of Structure, 205 Union Station, Terminal R. R., residence, 514 N. Spring Ave, St. Louis, Mo.	June 27, 1895
Hewitt, Charles E.	Electrician, Hyer-Sheehan Electric Motor Co., 139 Chamber St., Newburgh, N. Y.	Sept. 25, 1895
Hewitt, William R.	Superintendent, Fire Alarm and Police Telegraph, 9 Brenham Place, San Francisco, Cal.	May 15, 1894

Name.	Address.	Date of Election.
Hewlett, Edward M.	Engineer, General Electric Co., residence, 27 University Place, Schenectady, N. Y.	May 19, 1891
Hildburgh, Walter Leo	Student, Columbia University; c/o D. H. Hildburgh, Hotel Normandie, New York.	Dec. 28, 1898
Hill, Ernest Rowland	Electrical Engineer, Westinghouse E. & M. Co., Pittsburg, Pa,	Jan. 25, 1899
Hill, George, *C.E.*	Consulting Engineer, 150 5th Ave., Tel. 2326 18th., New York City.	April 19, 1892
Hill, G. Henry	Engineer, Sprague Electric Co., 527 W. 34th St., New York City; residence, 11 Hamilton Road, Glen Ridge, N J.	Jan. 25, 1899
Hill, Nicholas S., Jr.	Consulting Engineer, 520 Equitable Bldg., Baltimore, Md., and 100 William St., New York City.	Aug. 5, 1896
Hitzeroth, L. D.	Superintendent, Electrical Department General Electric Co., 229 Stevenson St.; residence, 452 Bryant St., San Francisco, Cala.	July 26, 1900
Hoag, Geo. M.	City Electrician, City of Cleveland, 113 City Hall; residence, 317 Hough Ave., Cleveland, O.	April 28, 1897
Hodge, William B.	Electrical Engineer, Queen & Co., 1010 Chestnut St., Philadelphia, Pa.	Dec. 28, 1898
Hoffmann, Bernhard	New York Telephone Co., 113 W. 38th St., residence, 12 W. 18th St., New York City.	Nov. 23, 1898
Holberton, George C.	Oakland Gas Light and Heat Co., Oakland, Cal.	May 15, 1894
Holbrow, Herman L.	Draughtsman, Equipment Dept., Navy Yard; residence, 112 Waverly Ave., Brooklyn, N. Y.	Mar. 24, 1897
Holmes, Gwyllyn R.	Holmes-Rose Electric Co., No. 215 Calvert St., residence 2842 Parkwood Ave., Baltimore, Md.	Jan. 24, 1900
Holt, Marmaduke Burrell,	Mining and Electrical Engineer, Silverton, Col.	April 15, 1890
Hommel, Ludwig	Supt. of Construction, Standard Underground Cable Co., 618 Westinghouse Bldg, Pittsburg, Pa	Jan. 20, 1897
Hood, Ralph O.	Electrical Engineer, Danvers, Mass.	April 18, 1894
Hopewell, Chas. F.	Inspector of Wires, Supt. of Lamps, Fire Alarm and Police Telegraph, City of Cambridge, City Hall; residence, 82 Magazine St., Cambridgeport. Mass.	Aug. 13, 1897
Hopkins, Nevil Monroe, *M.Sc.*	Electro-Chemist and Electro-Chemical Engineering Instructor in Chemistry and Electro Chemistry, in the Columbian University, 1730 I Street, Washington, D. C.	Nov. 20, 1895
Hopkins, N. S.	Designing Engineer, General Electric Co., Lynn, Mass.	April 27, 1898

Name.	Address.	Date of Election.
Horn, Harold J.	Electrical Engineer, John A. Roebling's Sons' Co ; residence, 36 W. State St., Trenton, N. J.	Mar. 22, 1899
Hosmer, Sidney	Electrical Engineer, Boston Electric Light Co , Ames Building, Boston, Mass.	May 18, 1897
Howe, Winthrop Keith	Assistant Engineer, Taylor Signal Co., Carroll and Wells Sts., Buffalo, N. Y.	Mar. 22, 1901
Howes, Robert	Asst. Supt. of the Light and Power System of Washington Water Power Co., Box 1587, Spokane, Wash.	Jan. 25, 1901
Howland, Lewis A.	Engineering Department, Canadian General Electric Co., Ltd., 6 Queen St., Montreal, Que.	July 26, 1900
Howson, Hubert	Patent Lawyer, 38 Park Row, New York City.	June 8, 1887
Hoxie, George L.	Student in Electrical Engineering, Cornell University, 1192 Cascadilla Place, Ithaca, N. Y.	Feb. 28, 1901
Hubbard, Albert S.	Gould Storage Battery Co., Astor Court B'ld'g, 25 W. 33rd St., residence, Belleville, N. J.	Nov. 20, 1895
Hubbard, William C.	Vice-President, Electric Arc Light Co., Sales Manager Manhattan General Construction Co., 11 Broadway, New York, residence, 427 West 7th St., Plainfield, N. J.	April 18, 1894
Hubrecht, Dr. H. F. R.	Director, Nederlandsche Bell Telephone Co., Amsterdam, Holland.	Oct. 4, 1887
Huggins, N. W.	Salesman, etc., General Electric Co., Seattle, Wash.	Aug. 5, 1896
Huguet, Chas. K.	Electrical Engineer, 731 Jackson Boulevard, Chicago, Ill.,	June 27, 1895
Hulse. Wm. S.	Electrical Engineer, with Union Elektricitäts Gesellschaft, Doratheen Str. 43, Berlin, Germany.	Mar. 25, 1896
Humphreys, C. J. R.	Manager, Lawrence Gas Co., and Edison Electrical Ill. Co., Lawrence, Mass.	Sept. 6, 1887
Hunt, Arthur L.	Harrisburg Foundry and Machine Works, 203 Broadway, New York City.	Sept. 19, 1894
Hunt, A. M.	Consulting Engineer, 331 Pine Street, San Francisco, Cala.	Feb. 28, 1900
Huntley, Chas. R.	General Manager, Buffalo General Electric Co., 40 Court St., Buffalo N. Y.	Sept. 25, 1895
Hutton, Chas. William	Chief Electrician, Sacramento Electric Gas and Railway Co., Sacramento, Cal.	Feb. 15, 1899
Hutchinson, Frederick L.	Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	June 20, 1894

Name.	Address.	Date of Election.
Hyde, J. E. Hindon	Patent Lawyer, 120 Broadway, New York City.	Jan. 24, 1900
Idell, Frank E.	Havemeyer Building, 26 Cortlandt St., New York City.	July 12, 1887
Ihlder, John D.	Electrical Engineer, Otis Electric Co., Yonkers, N. Y.	Oct. 2, 1888
Iijima Zentaro,	Electrical Engineer, Shibaura Engineering Works, 1 Shinhamacho, Shiba, Tokyo, Japan.	Jan. 22, 1896
Imlay, L. E.	Resident Engineer, Westinghouse Elec. & M'f'g. Co., 203 Sixth St., Niagara Falls, N. Y.	July 26, 1900
Insull, Martin J.	2d Vice-President and General Manager, General Incandescent Arc Light Co., New York, residence, 262 W. 83d St., New York City.	Nov. 22, 1899
Insull, Samuel	President, Chicago Edison Co., 139 Adams St., Chicago, Ill.	Dec. 7, 1886
Iwadare, Kunihiko	Electrician, Nippon Electric Company, 2 Mita Shikokumachi Shibaku, Tokyo, Japan.	Sept. 20, 1893
Jackson, E. D.	82 Beech St., Detroit, Mich.	Nov. 22, 1899
Jackson, Wm. Steell	4th Assistant Examiner, Patent Office; residence, 325 Spruce St., N. W., Washington, D. C.	April 22, 1896
Jaeger, Charles L.	Inventor, Maywood, N. J., Electric Recording Ship Apparatus, Laboratory, 132 Mulberry St., New York, N. Y.	Dec. 20, 1893
James, Henry Duvall,	*B. S.*, *M. E.* Engineering Dep't, Otis Elevator Co, 71 Broadway, New York; residence, 100 Buena Vista Ave., Yonkers, N. Y.	Nov. 23, 1898
Jaquays, Homer M.	Lecturer in Mechanical Engineering, McGill University, residence, 862 Sherbrooke St., Montreal, Quebec.	Dec. 27, 1899
Johnson, Albert C.	Superintendent and Electrician, Electric Light & Water Works, Box 7, Willmar, Minn.	May 16, 1899
Johnson, Charles E.	Compania Ferrocarilles del Districto Federal, Indianilla Mexico, D. F.	May 15, 1900
Johnson, Howard S.	Jeffrey M'f'g Co., 303 Kanawha St., Charleston, W. Va.	Mar. 22, 1899
Johnson, Wallace Clyde	Chief Engineer, The Niagara Falls Hydraulic Power and M'f'g Co., Niagara Falls, N. Y.	Mar. 22, 1901
Johnston, Thos. J.	Counsel in Patent Causes, 66 Broadway, New York City.	May 16, 1899
Johnston, W. J.	Publisher *Mining and Metallurgy*, 95 Liberty St., New York.	April 15, 1884
Jones, Arthur W.	Managing Director, Australian General Electric Co., Equitable Bldg., Melbourne, Australia.	Oct. 17, 1894

Name.	Address.	Date of Election.
Jones, Forrest R.	Professor of Drawing and Machine Design, Worcester Polytechnic Institute, residence, 3 State St., Worcester, Mass.	May 20, 1890
Jones, G. H.	Agent, General Electric Co., Casilla 1317 Santiago, Chile.	April 17, 1895
Jones, Henry C.	Member of Firm, the Electric Construction and Supply Co., Montgomery, Ala.	Mar. 20, 1895
Jones, M. E.	Chief Engineer, St. Lawrence State Hospital, Ogdensburg, N. Y.	Oct. 27, 1897
Joslyn, Howard.	Assistant Engineer, Snoqualmie Falls Power Co., 507 Pioneer Bldg, Seattle, Wash.	May 17, 1898
Judson, Wm. Pierson	Deputy State Engineer, of New York, Albany; residence, Oswego, N. Y.	June 8, 1887
Kammerer, Jacob A.	General Agent, The Royal Electric Co.; residence, 87 Jameson Ave., Toronto, Ont.	April 28, 1897
Keefer, Edwin S.	Supt. of Electric Light Construction, Western Electric Co., 463 West St., New York City; residence, Elizabeth, N. J.	April 18, 1894
Keilholtz, P. O.	General Manager, United Electric Light and Power Co., and Chief Engineer, United Railways and Electric Co., 330 N. Charles St., Baltimore, Md.	Mar. 21, 1893
Keller, E. E.	Vice-Prest. and General Manager, Westinghouse Machine Co, Pittsburg, Pa.; residence, Edgewood Park Pa.	Sept. 20, 1893
Kellogg, James W., *M.E.*	Manager Marine Sales, General Electric Co., residence, 10 Front St., Schenectady, N. Y.	June 26, 1891
Kelly, John F.	The Stanley Electric Co.; residence, 284 West Housatonic St., Pittsfield, Mass.	May 16, 1899
Kelsey, James Cezanne	Switchboard Trouble Mgr. N. W. Telephone Exchange Co., Minneapolis Minn.	Nov. 23, 1900
Kennedy, A. P.	Electrical Engineer, Norton Bros., 312 N. 3rd Ave., Maywood, Ill.	Apr. 26, 1899
Kennedy, Jeremiah J.	Mechanical Engineer with J. G. White & Co., 29 Broadway, New York.	July 26, 1900
Kent, James Martin	Instructor in Steam and Electricity, Manual Training High School, Kansas City, Mo.	July 26, 1900
Ker, W. Wallace	Instructor of Electricity, Hebrew Technical Institute, 36 Stuyvesant St., New York City. Residence, 626 Pavonia Ave., Jersey City, N. J.	Sept. 25, 1895

Name.	Address.	Date of Election.
King, Vincent C., Jr.	With V. C. & C. V. King, 517 West St.; residence, 110 East 16th Street, New York.	Aug. 5, 1896
Kinsley, Carl	Electrical Engineer, with Chicago Bell Telephone Co., 203 Washington St., Chicago.	May 18, 1897
Kittler, Dr. Erasmus	Professor at the Technical High School, Darmstadt, Germany.	Dec. 16, 1896
Klauder, Rudolph H.	Electrical Engineer, 817 Wainwright Bldg, St. Louis, Mo.	Aug. 13, 1897
Klinck, J. Henry	Klinck and Kodjbanoff, 5 So. 9th St. Reading, Pa.	Jan. 16, 1895
Knox, Frank H.	Engineer, Spartanburg Railway, Gas & Electric Co., Spartanburg S. C.	June 20, 1894
Knox, Geo. W.	2329 Magnolia Ave., Chicago, Ill.	Nov. 18, 1896
Knox, S. L. G.	Mechanical Engineer, General Electric Co.; residence, 29 Front St., Schenectady, N. Y.	Nov. 23, 1898
Kreidler, W. A.	Editor and Publisher, *Western Electrician*, 510 Marquette Building, Chicago, Ill.	Oct. 4, 1887
Kruesi, August H.	Designing Engineer, General Electric Co.; residence, 16 Union Street, Schenectady, N. Y.	Jan. 9, 1901
Lafore, John Armand	Electrical Engineer, The D'Olier Engineering Co., 125 South 11th St.; residence, Overbrook, Philadelphia, Pa.	May 15, 1900
Lamb, Richard	Chief Engineer, Brooklyn Dock and Terminal Co., and the Brigantine Trolley Co., 136 Liberty St.; residence, Waterwitch Park, Highlands, N. J.	Dec. 18, 1895
Land, Frank	Sec'y and Treas., I. A. Weston Co., residence, 102 Highland Ave., Syracuse, N. Y.	Sept. 22, 1891
Lanman, William H.	Board of Patent Control, 120 Broadway, New York City.	June 6, 1893
Lanphear, Burton S.	Assistant Professor of Electrical Engineering, Iowa State College, Ames, Iowa.	Jan. 16, 1895
Lansingh, Van Rensselaer	Electrical Engineer, Western Electric Co.; residence, 1018 E. 59th St., Chicago, Ill.	Aug. 23, 1899
Latham Harry Milton	With American Steel and Wire Co., Worcester, Mass.	Dec. 16, 1896
Lawrence, Wm. G.	Manager of Light and Power Department. Town of Hudson, Hudson, Mass.	Feb. 28, 1900
Lawrence, W. H.	Assistant Superintendent, Second District, Edison Electric Illuminating Co., 49 West 26th St., New York, N. Y.	April 26, 1899
LeBlanc, Charles	Engineer, 7 Rue Meyerbeer, Paris, France.	April 17, 1895

Name.	Address.	Date of Election
LeClear, Gifford,	Electrical and Mechanical Engineer, Partner Densmore & Le Clear, 15 Exchange Street. Boston, Mass.; residence. Cambridge, Mass.	Oct. 27, 1897
LeConte, Joseph Nisbet	Instructor in Electrical Engineering, State University, Berkeley, Cal.	Feb. 27, 1895
Ledoux, A.R., *M. S.*, *Ph.D.*,	President of Ledoux & Co.(inc.), 99 John St., residence, 39 W. 50th St., New York City.	Dec. 7, 1886
Lee, Francis Valentine	T. Engineer, (Pacific Coast Dept.) Stanley Electric M'f'g. Co., 33 New Montgomery St., San Francisco, Cal.	Mar. 23, 1898
Lee, John C.	Chemist and Electrician, American Bell Telephone Co., Boston residence. Mountfort St., Longwood, Brookline, Mass.	Mar. 18, 1890
Leeds, Norman	Electrical Engineer, Western Electric Co., 463 West St., New York; residence, Stamford, Conn..	Feb. 28, 1901
Leeds, Morris Evans	Managing Member of the firm, Morris E. Leeds & Co., 259 North Broad St.; residence, 3221 N. 17th St., Philadelphia, Pa.	Apr. 26, 1901
Leitch, Howard Wallack	Switchboard Regulator. The Edison Elect. Illuminating Co., residence, 373 Madison St., Brooklyn, N. Y.	Nov. 23, 1898
Lemon, Charles,	Hon. Sec'y for New Zealand for the Institution of Electrical Engineers, Waerenga Road, Otaki, New Zealand.	Jan. 22, 1896
Lethrule, Paul	Electrical Engineer, Commissioned by French Government, 27 Rue de Londres, Paris, France.	May 17, 1898
Lewis, Henry Frederick William,	Redlands, 48 Sydenham Road, Croydon, Surrey, England.	Mar. 5, 1889
Libby. Samuel Byington	Richmond Borough Equipment Co., 395 Richmond Terrace,New Brighton, N. Y.	Feb. 23, 1898
Lilley, L. G.	Electrician, The Cincinnati Underwriters' Association S. W. Cor. 3d and Walnut Sts., Cincinnati, O.; residence, Wyoming, O.	June 20, 1894
Lindsay, Robert	General Supt. The Cleveland Elec. Ill. Co., 717 Cuyahoga Building, Cleveland, Ohio.	April 27, 1898
Lisle, Arthur Beymer	General Representative, Narragansett Electric Lighting Co., Box 1223, Providence, R. I.; residence, East Greenwich, R. I.	Jan. 9, 1901
Little, C. W. G.	Engineering Manager, The British Electric Traction Co., Ltd., Donington House, Norfolk St., Strand, W. C., London, Eng.	April 22, 1899
Livingston, Johnston Jr.	The United Engineering and Contracting Co., 13 Park Row, New York City.	May 17, 1898

Name.	Address	Date of Election.
Livsey, J. H.	Salesman and Manager Detroit Office General Electric Co., 704 Chamber of Commerce, Detroit, Mich.	April 25, 1900
Loewenthal, Max	Supt. Osterberg and Sutton, 11 Broadway; residence, 100 St. Nicholas Ave., New York City.	Mar. 23, 1898
Lohmann, R. W.	With General Electric Co.; residence, 25 Front St., Schenectady, N. Y.	Nov. 23, 1898
Lorimer, Geo. Wm.	Sec'y and Treasurer, The American Machine Telephone Co., Ltd., Piqua, O.	Aug. 5, 1896
Lorimer, James Hoyt	Electrical Engineer and President, The American Machine Telephone Co., Ltd., Piqua. O.	Aug. 5, 1896
Louis, Otto T.	Manager of New York Branch, Queen & Co., Inc.; residence, 340 East 119th St., New York City.	Feb. 23, 1896
Lovejoy, D. R.	Electrical Engineer, c/o Cataract Chemical Co., Niagara Falls, N. Y.	April 28, 1897
Low, George P.	Editor and Proprietor, *Journal of Electricity, Power and Gas*, 320 California St., San Francisco, Cal.	Jan. 17, 1893
Lowther, Christopher Meyer,	Sales Engineer Crocker-Wheeler Co., New York; residence, 168 Arlington Ave., East Orange, N. J.	Nov. 23, 1900
Lundell, Robert	Electrical Engineer, 527 W. 34th St., residence, 9 W. 68th St., New York City.	Feb. 7, 1890
Lundie, John	Consulting Engineer, 52 Broadway, New York City.	Nov. 22, 1899
Lyford, Oliver S., Jr.,	Electric Boat Co., 100 Broadway, New York, N. Y.	Apr. 26, 1899
Lyman, Chester Wolcott, *M. A.*	Assistant to President International Paper Co., 30 Broad St., residence, University Club, New York, N. Y.	Sept. 19, 1894
Lynn, Wm. A.	Instructor in Electrical Engineering, University of California. Berkeley, Cal.	Jan. 25, 1899
Lyons, Joseph,	Patent Solicitor, with Gustav Bissing 908 G. St., Washington, D. C.	June 24, 1898
Macartney, John F.	Managing Director, Macartney, McElroy & Co, L't'd., 53 Victoria St., London, Eng.	May 16, 1899
MacFadden, Carl K.	Consulting Engineer, Geneva, Ind.	Sept. 27, 1892
MacGregor, Willard H.	General Eastern Agent, Cutler-Hammer, Mfg. Co. of Chicago. 136 Liberty St.; residence, 359 W. 27th St., New York City.	Jan. 20, 1897
MacLeod, George	Superintendent and Engineer, Kentucky and Indiana Bridge Co., 29th and High Sts.; residence, 1913 4th Ave., Louisville, Ky.	Aug. 5, 1896

Name.	Address.	Date of Election.
MACOMBER, IRWIN JOHN	Professor of Electrical Engineering Armour Institute of Technology, residence, 422 34th Street, Chicago, Ill.	Mar. 28, 1900
MAGEE, LOUIS J.	Electrical Engineer, Director, der Union Elektricitats Gesellschaft, Grosse Quer Allee 1., Berlin, Germany.	April 2, 1889
MAGNUS, BENJAMIN	Electrical Engineer, Ref. Dept., Anaconda Copper Mining Co., Anaconda, Mont.	Jan. 24, 1900
MAHONEY, JAMES J.	Engineer General Electric Co., 44 Broad St., New York City.	May 17, 1898
MAKI, HEIICHIRO	Chief Engineer, Hōshyū Traction Co., Beppu, Oitaken, Japan.	Aug. 5, 1896
MANSFIELD, R. H. Jr.,	Eastern Manager of the Cutler-Hammer Mfg. Co., Westfield, N. J.	Sept. 28, 1898
MARSH, HARRY BOWMAN	President, The Advance Electric Co., 8 West Market St., Indianapolis, Ind.	Mar. 28, 1900
MARSHALL, CLOYD	Designer of Electrical Machinery, Lafayette Ind.	Apr. 25, 1900
MARTIN, FRANK	Electrician, Dept. Yards and Docks, New York Navy Yard; residence, 161 Cumberland St., Brooklyn, N.Y.	Oct. 21, 1890
MARTIN JOHN	Agent, Stanley Electric M'fg. Co., 33 New Montgomery St., San Francisco, Cal.	July 27, 1898
MARTIN, T. COMMERFORD	(*Past-President.*) Editor, *The Electrical World and Engineer*, 120 Liberty St., N. Y. City.	April 15, 1884
MASSON, RAYMOND S.	Salesman and Engineer, Westinghouse E. & M. Co., 327 Market St., San Francisco, Cal.	Apr. 26, 1899
MATHER, EUGENE HOLMES	Manager Cumberland Ill. Co. and Portland Electric Light Co., Portland, Me	April 28, 1897
MATTHEWS, CHARLES P.	Associate Professor, Electrical Engineering, Purdue University, residence, Thornell St., Lafayette, Ind.	May 16, 1893
MAXWELL, EUGENE	c/o. Snoqualmie Falls Power Co., Seattle, Wash.	Aug. 5, 1896
MAURO, PHILIP	Counsellor at-Law in Patent Causes (Pollock & Mauro), 620 F. St., Washington, D. C.	Dec. 21, 1892
MAYER, MAXWELL M.	Mfr. of Plating Dynamos, 2369 2d Ave., residence 433 East 116th St., New York City.	Feb. 27, 1895
MCCARTER, ROBERT D. JR.	Electrical Engineer, General Electric Co., 110 Cannon St., London, E. C.	May 16, 1899
MCCARTHY, E. D.	McCarthy Bros. & Ford, 45 North Division St.; residence, 382 West Ferry Street, Buffalo, N. Y.	Nov. 18, 1896

Name.	Address.	Date of Election.
McClenathan, Robert	Mechanical and Electrical Engineer, With General Electric Co., Schenectady, N. Y.	May 16, 1899
McCluer, Chas. P.	Wm. R. Trigg Co., Shipbuilders, Richmond, Va.	Apr. 22, 1896
McClure, William J.	Associated with H. D. Brown, Electrical Engineers and Contractors, residence, 259 West 52nd St., New York City.	Apr. 25, 1900
McClurg, W. A.	Manager, Electrical Dept., Plainfield Gas and Electric Light Co., 207 Madison Ave., Plainfield, N. J	Dec. 20, 1893
McCreary, J. L.	Constructing Engineer, District Railway Co., Mexico City.	Feb. 28, 1900
McElroy, James F.	Consulting Engineer, Consolidated Car Heating Co., 131 Lake Ave., Albany, N. Y.	Nov. 15, 1892
McKissick, A. F.	Engineer, Pelzer Manufacturing Co., Pelzer, S. C.	Feb. 16, 1892
McLain, Ralph Clapp	Assistant Engineer, Rapid Transit Subway Construction Co., 21 Park Row, residence, 170 W. 59th St , New York N. Y.	Aug. 23, 1899
McLimont, A. W.	Federal Electric Co., '41 Broadway, New York, N. Y.	July 26, 1900
McVay, H. D.	Supt. Overton M'f'g. and Engineering Co., 111 E. 7th St., Topeka, Kan.	Feb. 28, 1900
Meadows, Harold Gregory	Associate Engineer (Elec.) with Newcomb Carlton, 109 White Building; residence, 238 Elmwood Ave., Buffalo, N. Y.	Sept. 23, 1896
Meredith, Wynn	Electrical Engineer, Benjamin, Hunt, and Meredith, 331 Pine St., San Francisco, Cal.	Jan. 17, 1893
Merrill, E. A.	Manager, New York Office, McIntosh, Seymour & Co., 26 Cortlandt St., New York City.	Sept. 20, 1893
Merrill, Josiah L.	Electrical Engineer, c/o. General Railway Supply Co., Park Bldg, Pittsburg, Pa.	Sept. 25, 1895
Merz, Chas. H.	The Cork Electric Tramways and Lighting Co Ltd., Cork; residence, The Quarries, Newcastle-on-Tyne, England.	Sept. 25, 1895
Meyer, Hans S.	Electrical Engineer, Alleestrasse 7D Hannover, Germany.	July 27, 1889
Meyer, Julius	Consulting Engineer, 115 Broadway, Room 124, New York City.	Oct. 25, 1892
Middleton, A. Center	General Electric Co , 420 W. 4th St , Cincinnati, O.	May 16, 1899
Miller, Herbert S.	Electrical Engineer, Diehl Mfg. Co.; residence, 1025 E. Jersey St., Elizabeth, N. J.	Mar. 22, 1899

Name.	Address.	Date of Election
Miller, Kempster B.	Engineer Kellogg Switchboard and Supply Co., Congress and Green St., residence, 2060 Kenmore Ave., Chicago, Ill.	Sept. 28, 1898
Miller, Wm. C., *M. S.*	Electrical Engineer, 3 South Hawk St., Albany, N. Y.	Oct. 21, 1890
Misaki, Seizo	Chief Engineer and Superintendent Hanshin Elec. Railway Co., Nishinomiyo. Hiogo Ken, Japan.	Dec. 27, 1899
Mitchell, Sidney Z.	Manager, Portland Office, General Electric Co., Worcester Building, Portland, Ore.	Nov. 12, 1889
Mole, Harvey Edward	with J. G. White & Co., 29 Broadway, New York City.	Nov. 30, 1897
Monrath, Gustave	Engineer and Superintendent, Grace and Hyde Engineering Co., 7 E. 42d St., New York City.	Apr. 26, 1901
Montagu, Ralph Lechmere	Continental Gold Dredging Co., Oroville, Cal.	Feb. 26, 1896
Moody, Virginius Daniel	609 State St., Schenectady, N. Y.	Dec. 27, 1899
Moore, John Peabody	General Electric Co , Box, 389, Schenectady, N. Y.	Apr. 25, 1900
Mora, Mariano Luis	General Electric Co., 44 Broad St., New York City.	Mar. 20, 1895
Mordey, Wm. Morris	Consulting Electrician, 82 Victoria St., Grosvenor Mansions. Westminster, London, Eng.	Sept. 22, 1891
Morehead, J. M.	Engineer, Union Carbide Co., 157 Michigan Ave., Chicago, Ill.	Mar. 28, 1900
Morehouse, H. H.	Morehouse and Morrill, General Electric Installation and Contracting Work, Apartado No 44, Quezaltenango, Guatemala, C. A.	Feb. 21, 1894
Morgan, Chas. H.	4th Ass't Examiner, U. S. Patent Office, residence, 43 R. St., N. W. Washington, D. C.	Aug. 5, 1896
Morgan, Jacque L.	City Electrician, City Hall, residence, 1702 Locust St., Kansas City, Mo.	Jan. 26, 1898
Morley, Edgar L.	Sup't Hatzel & Buehler, 114 5th Ave., New York City.	Sept. 25, 1895
Morrison, J. Frank	Manager, The Northern Electric Co. 15 South St., Baltimore, Md.	April 15, 1884
Mortimer, James D.	Instructor in Electrical Engineering, University of California, Mechanics' Building, Berkeley, Cala.	Mar. 28, 1900
Mortland, James A.	Sergeant 12th Co., U. S. V., Signal Corps, Official Photographer, 3d Army Corps, Montezuma, Iowa.	Feb. 23, 1898
Morton, Henry, *Ph.D.*	President of Stevens Institute of Technology, Hoboken, N. J.	May 24, 1887
Moschkowitsch, Meers	S. Preobrajenska, 53. Odessa, Russia.	Jan. 9, 1901
Moses, Percival Robert, *E. E.*	Electrical Engineer, 35 Nassau St.: residence, 46 West 97th St., New York City.	Dec. 19, 1894

Name.	Address.	Date of Election
Mosscrop, Wm. A., *M.E*	Electrical Engineer, 47 Brevoort Place, Brooklyn, N. Y.	May 7, 1889
Mudge, Arthur Langley	Electrical Engineer, Grand Trunk Railway Co., Montreal, Canada.	Mar. 22, 1901
Mullin, E. H.	General Electric Co., 44 Broad St., residence, 1 West 102nd Street, New York, N. Y.	May 16, 1899
Murphy, John McL.	Electrical Engineer, Safety Third Rail Electric Co., 116 Nassau St., New York, N. Y.	Oct. 26, 1898
Muschenheim, Fred'k A.	Electrical Engineer, Western Electric Co., 463 West St.; residence, 41 W. 31st St., N. Y. City.	April 27, 1898
Namba, M.	Professor of Electrical Engineering, University of Kioto, Kioto, Japan.	Apr. 26, 1899
Naphtaly, Sam L.	Manager and General Superintendent, The Central Light and Power Co., Room 500, Parrott Building, residence, 2404 Broadway, San Francisco, Cal.	Aug. 23, 1899
Neilson, John	Larchmont, N. Y.	May 18, 1897
Neurath, Morris M.	Consulting Engineer, 1444 Monadnock Block, Chicago, Ill.	Feb. 26, 1900
Newbury, F. J.	Manager Insulated Wire Department, John A. Roebling's Sons Co., Trenton, N. J.	Sept. 23, 1896
Nicholson, Samuel L.	With Westinghouse Elec. & M'fg. Co., 120 Broadway, New York; residence, 820 President St., Brooklyn, N. Y.	July 26, 1900
Niles, Harry B.	Electrical Engineer, Ferrocarrillos del Distrito American Club, Mexico City.	Jan. 24, 1900
Nimis, Albert A.	Electrical Contractor, Nimis & Nimis, 59 East 5th Street, St. Paul, Min. and 1221 Lexington Ave., N. Y. City.	Aug. 13, 1897
Nock, Geo. W.	Chief Engineer, in charge of Steam and Electric Plant Westinghouse Elect. and Mfg. Co., Pittsburg, Pa.	Aug. 5, 1896
Noxon, C. Per Lee	Manufacturer, High-Frequency X-Ray Apparatus, Dynamos and Motors, 500 East Water Street, Syracuse, N. Y.	Oct. 17, 1894
Nunn, Richard J., *M. D.*	Physician, 5 York St. East, Savannah, Ga.	July 12, 1887
Nyhan, J. T.	Superintendent and Electrician, Macon Electric Light and Railway Co., Macon, Ga.	Feb. 27, 1895
Ockershausen, H. A.	Electrical Engineer, 65 Madison Ave., Jersey City, N. J.	Sept. 6, 1887

Name.	Address.	Date of Election.
OFFINGER, MARTIN HENRY	Head of Electro-Mechanical Dept., Buffalo Commercial & Electro Mechanical Institute, residence, 217 E. Eagle St., Buffalo, N. Y.	Mar. 28, 1900
OFFUTT, ANDERSON, *B.S.*, *E.E.*	Assistant Electrician, South Eastern Tariff Ass'n. Care Underwriters Inspection Bureau, New Orleans, La.	May 15, 1900
OI, SAITARO	Chief Engineer to the Bureau of Posts and Telegraphs The Ministry of Communications, Tokyo, Japan.	Dec. 28, 1898
OLIVETTI, CAMILLO	Ingegnere Industriale, Ivrea, Italy.	Oct. 17, 1894
OOLGARDT, J. J.	Electrical Engineer, (Foreign Dept.) General Electric Co.; residence, Edison Hotel, Schenectady, N. Y.	April 25, 1900
ORMSBEE, ALEX. F.	Electrical Engineer, with N. Y. and N. J. Telephone Co., 81 Willoughby St.; residence, 183 Joralemon St., Brooklyn, N. Y.	June 27, 1895
OSBORNE, LOYALL ALLEN	Manager of Works, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	Oct. 18, 1893
OSBORNE, MARSHALL	Engineer in charge of Contracts, The British Thomson-Houston Co., 83 Cannon St., London, Eng.	April 25, 1900
OSTERBERG, MAX, *E.E.*, *A.M.*	Consulting Engineer, and Electrical Expert, Bowling Green Building, New York City.	Jan. 17, 1894
O'SULLIVAN, M. J.	Superintendent, Electric Light, B. & O. R. R. Co., Sylvan Ave. near Hazelwood, Pittsburg, Pa.	Mar. 20, 1895
OTTEN, DR. JAN D.	Director, Batavia Electrische Tram-Maatschappij. Van Baerlstraat 80, Amsterdam. Holland.	Nov. 18, 1890
PAGE, A. D.	Assistant Manager, General Electric Co. Lamp Works, Harrison, N. J.	Jan. 19, 1892
PARKE, RODERICK J.	Consulting Electrical Engineer, 409 Temple Bldg., Toronto, Canada.	July 26, 1900
PARKER, HERSCHEL C.	Tutor in Physics, Columbia University, 21 Fort Green Pl., Brooklyn, N. Y.	April 19, 1892
PARMLY C. HOWARD, *S.M.*, *E.E.*	College of the City of New York, 17 Lexington Ave.; residence, 524 W. 114th St., New York City.	Feb. 21, 1893
PARRY, EVAN	Engineer, c/o. H.F. Parshall, 8 Princes St, Bank; residence, Sunningdale, Fitzgerald Ave., Mortlake, London, Eng.	Sept. 25, 1895
PARSELL, HENRY V. A. JR.	Electrical and Mechanical Designing and Experimental Work, 129 W. 31st St, residence, 31 E. 21st St., New York City.	Nov. 12, 1889
PARSHALL, AUGUST	Commercial Engineer, Supply Dept. General Electric Co., 83 Cannon St., London, E. C.	Oct. 24, 1900

Name.	Address.	Date of Election.
Patton, Price I.	The Bartram, 33d and Chestnut St., Philadelphia, Pa.	Mar. 20, 1895
Pearson, Fred'k J.	Consulting Electrical and Mechanical Engineer, Woodmen of the World Bldg., Omaha, Neb.	July 27, 1898
Peck, Edward F.	187 Montague St.; residence, 700 Nostrand Ave., Brooklyn, N. Y.	May 20, 1890
Peirce, Arthur W. K.	Consulting Electrical Engineer to the Consolidated Gold Fields of South Africa, Ltd., Box 217, Germiston, Transvaal.	June 27, 1895
PenDell, Chas. William	Electrical Dept., C. & N. W. R. R., 109 S. Pine Ave., Austin Station, Chicago, Ill.; residence, Cleburne, Texas.	Nov. 22, 1899
Perkins, Frank C.	Electrical Engineer, 126 Erie Co. Bank, 655 Prospect Ave., Buffalo, N. Y.	Oct. 21, 1890
Perry, John	President of I. E. E. (England) 34 Palace Gardens Terrace, London W. England.	Mar. 22, 1901
Petty, Walter M.	Superintendent Fire Alarm Telegraph, Rutherford, N. J.	May 16, 1893
Pfeiffer, Alois J. J.	Engineer, Thomson-Houston Co., 5 Piazza Castello Milano, Italy.	Jan. 24, 1900
Pfund, Richard	601 W. 169th St., New York City.	April 18, 1893
Phelps, Wm. J.	Manager, Phelps Manufacturing Co., Electrical Specialties, Elmwood, Ill.	Mar. 25, 1896
Philbrick, B. W.	Electrical Engineer for J. J. Astor, Rhinecliff, N. Y.	May 15, 1894
Phillips, Eugene F.	President, American Electrical Works, Phillipsdale, R. I.	July 13, 1889
Phillips, Leo A.	Superintendent Electrical Dept., Trade Dollar Consolidated Mining Co., Dewey, Idaho.	Mar. 21, 1894
Pillsbury, Chas. L.	Sup't Minneapolis International Electric Co., Edison Building, Sec'y State Board of Electricity, Minneapolis, Minn.	Aug. 13, 1897
Pinkerton, Andrew	Electrical Engineer, American Sheet Steel Co., Vandergrift Pa.	Sept. 25, 1895
Pomeroy, William D.	Supt, Akron Electrical Mfg. Co., 110 Park Place, Akron, O.	Mar. 22, 1899
Poole, Cecil P.	Editor *American Electrician*, 120 Liberty St., residence, 163 W. 84th St., New York City.	Jan. 3, 1888
Poole, Charles Oscar	Superintendent Electrical Dept., Standard Electric Co. of California, Crocker Bldg.; residence, 452 Bryant St, San Francisco, Cal.	Jan. 24, 1900
Pope, Henry William	Acting General Manager, Bell Telephone Co., of Buffalo; residence, 455 Richmond Ave, Buffalo, N.Y.	Mar. 23, 1898

Name.	Address.	Date of Election
POPE, RALPH WAINWRIGHT	Secretary to the American Institute of Electrical Engineers, 26 Cortlandt St., (Telephone, 2199 Cortlandt), New York City; residence, 570 Cherry St., Elizabeth, N. J.	June 2, 1885
PORTER, H. HOBART, JR.	Sanderson & Porter, 31 Nassau St., New York; residence, Lawrence, L. I.	Mar. 25, 1896
POWELL, PERCY HOWARD	*M. E.*, Bridgeport Brass Co.; residence, 530 State St., Bridgeport, Conn.	Sept. 25, 1895
POWELSON, WILFRED VAN NEST	Government Inspector, Electrical Appliances; Lieutenant U. S. Navy, Navy Yard, Brooklyn, N. Y.	Jan. 24, 1900
PRICE, CHAS. W.	Editor the *Electrical Review*, 13 Park Row, New York City; residence, 223 Garfield Place, Brooklyn, N. Y.	Sept 19, 1894
PRICE, EDGAR F.	Works Manager, Union Carbide Co., residence, 625 Buffalo Ave., Niagara Falls, N. Y.	June 27, 1895
PRINCE, J. LLOYD	Edison Illuminating Co., New York City; residence, 868 Flatbush Ave., (Flatbush Station), Brooklyn, N. Y.	Feb. 27, 1895
PROCTOR, THOS. L.	Marine Electrical Equipment, 39 Cortlandt St., New York; residence, Newtown, L. I., N. Y.	April 18, 1894
PROSSER, HERMAN A.	Asst. Supt. Guggenheim Smelting Co., Perth Amboy, N. J.	Jan. 26, 1898
PUPIN, DR. MICHAEL I.	Adjunct Professor in Mechanics, Columbia University; residence, 280 North Broadway, Yonkers, N. Y.	Mar. 18, 1890
RAMSEY, HARRY NATHAN	Draughtsman, (and Designer) with Taylor Signal Co., 32 Wells St., Buffalo; residence, 311 East Henley St., Olean, N. Y.	May 16, 1899
RANDALL, JOHN E.	Columbia Incandescent Lamp Co., 1912 Olive St., St. Louis, Mo.	May 7, 1889
RANDOLPH, L. S.	Professor of Mechanical Engineering, Blacksburg, Va.	Feb. 21, 1893
RATHENAU, ERICH	Electrical Engineer, Allg. Elektricitats Gesellschaft, Berlin, Germany.	Nov. 20, 1895
RAUB, CHAS. B.	Electrical Engineer, Thames Electric Co., New London, Conn.	Nov. 22, 1899
RAY, WILLIAM D.	1626 Marquette Building, Chicago, Ill.	Sept. 27, 1892
READ, ROBERT H.	Patent Attorney, General Electric Co., Schenectady, N. Y.	Jan. 19, 1892
REED, CHAS. J.	Electrician, 3313 N. 16th St., Philadelphia, Pa.	Mar. 5, 1889
REED, HARRY D.	Superint'd't Bishop Gutta Percha Co., 420 East 25th St., New York City; residence, 88 North 9th St., Newark, N. J.	Sept. 19, 1894

Name.	Address.	Date of Election.
Reed, Henry A.	Secretary and Manager, Bishop Gutta-Percha Co., 422 East 25th St., New York City; residence, 88 North 9th St., Newark, N. J.	June 4, 1889
Reed, Walter Wilson	Electrical Engineer in charge of the electrical work of new plant Citizen Electric Light and Power Co., Houston, Texas.	Apr. 26, 1899
Reichmann, Fritz	Ryerson Physical Laboratory, University of Chicago, Chicago, Ill.	Mar. 23, 1898
Reid, Edwin S.	General Sup't of Construction, National Conduit and Cable Co , 23 College Hill, Cannon St., E. C., London, Eng.	Feb. 26, 1896
Reilly, John C.	General Supt., N. Y. & N. J. Tel. Co., 16 Smith St., Brooklyn, N. Y.	April 15, 1884
Rennard, John Clifford, *A. B. E. E.*	Consulting and Supervising Electrical Engineer, 15 Dey St., New York City.	Jan. 16, 1895
Renstrom, Frans Oscar	Superintendent, The Regla Power Co., Apartado 95, Pachuca, Mexico.	Feb. 28, 1900
Rice, Arthur L.	Professor of Steam and Electrical Engineering, Pratt Institute, residence, 114 Cambridge Place, Brooklyn, N. Y.	Oct. 21, 1896
Rich, Francis Arthur	Manager, Woodstock G. M. Co., Karangahake, Auckland, New Zealand.	Jan. 20, 1897
Richards, Chas. W.	C. W. Richards & Co., 178 Devonshire St, Boston; residence, Needham, Mass.	Sept. 23, 1896
Richey, Albert S.	Electrician, Union Traction Co., of Indiana, 215 W. 9th St., Anderson, Ind.	May 18. 1897
Rideout, Alexander C. *LL. D.*	Consulting Electrical and Mechanical Engineer, Rideout & Gage, 101 Randolph St., Chicago, Ill.	Aug. 5, 1896
Ripley, Wm. Howe	Ripley & Arendt, 24 Murray St.; residence, 17 W. 123d St., New York City.	Feb. 17, 1897
Roberson, Oliver R.	Electrician, Western Union Telegraph Co., 195 Broadway, P O. Box 856, New York City.	Dec. 20, 1893
Roberts, Allen Davidson	Electrician, 12½ King St., Kingston, Jamaica.	Nov. 22, 1899
Robertson, Jas. McCallum	Superintendent, Power Department, The Royal Electric Co., 94 Queen St., Montreal, P. Q.	Apr. 26, 1901
Robinson, Almon	Webster Road, P. O. Box 943, Lewiston, Me.	Sept. 6, 1887
Robinson, Arthur L.	Electrical Engineer, Southern Railway Co., Washington, D. C.	May 15, 1900
Robinson, Dwight Parker	Assistant General Manager, The Seattle Electric Co., 815 2nd Ave., Seattle, Wash.	Sept. 25, 1895

Name.	Address.	Date of Election.
ROBINSON, FRANCIS GEORGE	With Metropolitan Street Railway Co.; residence, Hotel Richelieu, 114th St. & Fifth Ave., New York City.	Nov. 21, 1894
ROBINSON, GEO. P.	Ass't Supt. L. D. Service, The Wisconsin Telephone Co., 498 Milwaukee St., Milwaukee Wis.	May 16, 1899
ROCKWOOD, DWIGHT CARRINGTON	Student, Westinghouse Electric and M'f'g. Co., Box 104, Edgewood Park, Pa.; residence, 954 Main St., Buffalo, N. Y.	Mar. 22, 1901
ROEBLING, FERDINAND W.	Manufacturer of Electrical Wires and Cables, Trenton, N. J.	June 8, 1887
ROLLER, FRANK W. *M.E.*	Electrical Engineer, Machado & Roller, Electrical Machinery, 203 Broadway, N. Y.; residence, Roselle, N. J.	May 21, 1895
ROPER, DENNEY W.	Supt. Electrical Equipment, Missouri-Edison Electric Co., American Central Bldg., St. Louis; residence, Alton, Ill.	June 6, 1893
ROSEBRUGH, THOMAS REEVE	Lecturer in Electrical Engineering, School of Practical Science, 666 Spadina Ave., Toronto, Ont.	June 26, 1891
ROSENBAUM, WM. A.	Electrical Expert and Patent Solicitor, 177 Times Building, New York City.	Jan. 3, 1889
ROSENBERG, E. M., *M. E.*	Residence, 138 W. 85th St., New York City.	Oct. 21, 1890
ROSENBUSCH, GILBERT	Engineer, Sprague Electric Co., Bloomfield; residence, South Orange, N. J.	Sept. 28, 1898
ROSS, TAYLOR WILLIAM	The New York Shipbuilding Co.; residence, 527 Linden St., Camden, N. J.	Mar. 25, 1896
ROSSI, HAROLD J.	C. Victoria, Tamaulipas, Mexico.	Oct. 24, 1900
ROWLAND, ARTHUR JOHN	Professor of Electrical Engineeriug, Drexel Institute; residence, 4510 Osage Ave., Philadelphia, Pa.	Sept. 19, 1894
RUSHMORE, DAVID B.	Ass't Electrician Stanley Elec. and M'f'g Co., residence, 202 South St., Pittsfield, Mass.	Sept. 25, 1895
RUSHMORE, SAMUEL W.	Proprietor, Rushmore Dynamo Works, 24 Morris St., Jersey City, N. J.	Mar. 28, 1900
RUSSELL, H. A.	Sales Agent, General Electric Co., residence, 302 Laurel St., San Francisco, Cala.	Nov. 22, 1899
RUSTIN, HENRY	Chief of the Mechanical and Electrical Bureau, The Pan-American Exposition, Buffalo, N. Y.	Oct. 24, 1900
RUTHERFORD, WALTER	Manager Electric Traction Dep't, Dick Kerr & Co., Ltd., 110 Cannon St., London E. C., England.	Sept. 22, 1891

Name.	Address.	Date of Election.
Ryerson, Wm. Newton	Foreman, Metropolitan Street Railway Co., 146th St. and Lenox Ave.; residence, 200 West 92nd St., New York.	Aug. 23, 1899
Sage, Henry Judson	Sage & Co., Electrical Engineers, Rochester, Pa.	Dec. 20, 1893
Sahulka, Dr. Johann	Docent of Electrotechnics, Technische Hochschule, Vienna, Austria	Dec. 20, 1893
Sanborn, Francis N.	29 Wall St., New York City.	Nov. 24, 1891
Sanderson, Edwin N.	Of Sanderson & Porter, Engineers and Contractors, 31 Nassau St., New York City.	Oct. 17, 1894
Sanville, Henry F.	Secretary and Electrical Engineer, Morris Electric Co., Splice and Terminal Co, 15 Cortlandt St.; residence, 213 W. 105th St., New York.	Feb. 28, 1901
Sargent, Howard R.	Electrical Engineer, General Electric Co.; residence, 23 University Place, Schenectady, N. Y.	Mar. 25, 1896
Satherberg, Carl Hugo	Chief Engineer, The Midvale Steel Co., Nicetown, Phila., Pa.; residence 1752 N. 26th St., Philadelphia, Pa.	Aug. 5, 1896
Saxelby, Frederick	Electrical Engineer, Bullock Electric M'f'g. Co., 220 Broadway, New York; residence, 15 Whittlesey Ave., East Orange, N. J.	June 5, 1888
Saylor, Frederick Alexander [Life Member.]	Chief Electrician, U. S. S. Chicago; residence, Reading, Pa.	Jan. 24, 1900
Schlosser, Fred. G.	Superintendent of Electric Dept., Laclede Gas Light Co., 411 N. 11th St. Louis, Mo.	Sept. 22, 1891
Schmidt, Chas. J.	In Engineering Dept. as Telephone Engineer, Milwaukee Electric Railway and Light Co., Construction Dept., Milwaukee, Wis.	Jan. 9, 1901
Schoolfield, Frank Robert	Draughtsman, The United Railway and Electric Co., 15 South St.; residence, 738 W. Fayette St., Baltimore, Md.	May 16, 1899
Schreiter, Heinr. *C. E.*	Counsellor and Attorney, 20 Nassau St., New York City.	Jan. 17, 1893
Schum, Chas. H.	Electrical Engineer, with Bergmann Electromoteren and Dynamo Werke, Oudenarder Strasse, 23–30, Berlin, Germany.	Feb. 23, 1898
Schurig, Edward F.	City Electrician, The City of Omaha, 306 City Hall, Omaha, Neb.	Apr. 26, 1899
Schiaffino, Mariano L.	Chief Electrician, Compania de Luz Electrica, Guadalajara, Mexico.	Feb. 28, 1900
Schwab, Martin C.	Electrical Engineer, with Northern Electric Co., 15 South St.; residence 1729 Madison Ave., Baltimore, Md.	Nov. 18, 1896

Name.	Address.	Date of Election.
Schwabe, Walter P.	Superintendent Electrical Dept. Rutherford District, The Gas and Electric Co , of Bergen County, Rutherford, N. J.	May 19, 1896
Schweitzer, Edmund Oscar,	Electrical Inspector, Chicago Edison Co., 139 E. Adams St.; residence, 1906 Oakdale Ave., Chicago, Ill.	Feb. 15, 1899
Scidmore, Frank L.	With N. Y. C. & H. R. R. R. Co., office of A. F. A.; residence, 69 Ravine Ave., Yonkers, N. Y.	Dec. 18, 1895
Scott, Wm. M.	Electrical Engineer. The Cutter Electrical and Mfg. Co., 1112 Sansom St., Philadelphia, Pa.; residence, 108 West Johnson St , Germantown, Pa.	June 23, 1897
Scudder, Hewlett, Jr.,	21 East 22d St., New York City.	Nov. 22, 1899
Searing, Lewis	Vice-President and General Manager, Denver Engineering Works Co., 924 Washington Ave.,Denver, Col.	April 3, 1888
Searles, A. L.	Electrical Engineer, Fort Wayne Electric Works, Marquette Building, Chicago, Ill.	April 18, 1894
Sedgwick, C. E.	Manager, The Hilo Electric Light Co Ltd., Hilo, H. I.	Feb. 23, 1898
See, A. B.	A. B. See Manufacturing Co., 220 Broadway, New York City; residence, 107 East 19th St , (Flatbush), Brooklyn, N. Y.	Jan. 17, 1893
Selden, R. L. Jr.,	Deep River, Conn	Jan. 24, 1900
Serrell, Lemuel Wm.	Mechanical and Electrical Engineer, 99 Cedar St., New York City; residence, Plainfield, N. J.	Nov. 1, 1887
Sethman, George Henry,	Mechanical and Electrical Engineer, Skinner & Sethman, 2305 Boulevard F., Denver, Colo.	Nov. 23, 1900
Shaffner, S. C.	Supt. and Electrician. Electric Lighting Co. of Mobile, Box, 234, Mobile, Ala.	Aug. 13, 1897
Sharpe, E. C.	c/o John A. Roebling's Sons Co., 25 Fremont St., San Francisco, Cal.	Feb. 26, 1896
Shaw, Aubrey Norman	Draughtsman, A. B. See M'f'g Co., residence, 298 Carlton Ave., Brooklyn, N. Y.	Mar. 28, 1900
Shaw, Howard Burton	Professor Electrical Engineering, Missouri State University, Columbia, Mo.	April 28, 1897
Shearer, J. Harry	Electrical Engineer, National Electric Light Co., Apartado, 639 Mexico City, Mexico.	Jan. 24, 1900
Shepard, Roberto R.	Erecting Engineer. Mexican General Electric Co., Apartado 403, Mexico City, Mexico.	Jan. 24, 1900

Name.	Address.	Date of Election.
SHOCK, THOS. A. W.	Gen'l Sup't Portland General Electric Co., Portland, Or.	Mar. 20, 1895
SIMPSON, ALEXANDER B.	Electrical Engineer, 54 Maiden Lane, N. Y. City.	May 21, 1891
SIMPSON, J. MANLEY	Assistant to General Superintendent, Northwestern Grass Twine Co., P. O. Box 2513, St Paul, Minn.	Jan. 25, 1899
SISE, CHARLES F.	President, Bell Telephone Co., of Canada, P. O. Box 2262, Montreal, Canada.	June 8, 1887
SKINNER, CHARLES EDWARD	Electrical Engineer, Westinghouse E. & M. Co.; residence, 424 Franklin Ave., Pittsburg, Pa.	Apr. 26, 1899
SKIRROW, JOHN F.	Ass't Manager, Postal Telegraph Cable Co., New York City; residence, 183 N. 19th St., East Orange, N. J.	Sept. 25, 1895
SLADE, ARTHUR J., *Ph.D.*	Engineer, 289 4th Ave., New York City; residence, Elmora, Elizabeth, N. J.	Sept. 19, 1894
SLATER, FREDERICK R.	Asst. Electrical Engineer, Manhattan R'way., 32 Park Place, New York; residence, 153 Warburton Ave., Yonkers, N. Y.	Oct. 17, 1894
SLICHTER, WALTER I.	Electrical Engineer, General Electric Co.; residence, 234 Union St., Schenectady, N. Y.	April 25, 1900
SMITH, FREDERICK B.	Electrical Specialties, 170 Summer St., Boston, Mass.	July 26, 1900
SMITH, IRVING B.	Partner, Chas. Wirt & Co., 1028 Filbert St., Philadelphia, Pa.	May 15, 1900
SMITH, IRVING WILLIAMS	Electrician Bishop Gutta Percha Co., 420 E. 25th St; residence, 5 W. 90th St., New York.	Jan. 9, 1901
SMITH, J. BRODIE	General Manager, Manchester Electric Co. and Manchester Street Railway, 142 Merrimack St., Manchester, N. H.	Mar. 21, 1894
SMITH, OBERLIN	President and Mechanical Engineer, Ferracute Machine Co., Lochwold, Bridgeton, N. J.	May 19, 1891
SMITH, T. JARRARD	Manufacturers and Inventors' Electric Co., 96 Fulton St., Tel. 838 John, New York City; residence, Roselle, N. J.	April 19, 1892
SMITH, SAMUEL JAMES	Salesman and Installing Engineer, Crocker-Wheeler Co, 202 So. Tryon St., Charlotte, N. C.	Oct. 24, 1900
SMITH, WALTER EUGENE	Electrician, The United Electric Improvement Co., 19th and Allegheny Ave., residence, 2010 Ontario St., Philadelphia, Pa.	Feb. 28, 1900
SMITH, WALTER F.	General Manager, United Gas Improvement Co.; residence, 2010 Ontario St., Philadelphia, Pa.	July 26, 1900

Name.	Address.	Date of Election.
Smith, Wm. Lincoln	Instructor of Electrical Engineering. Mass. Inst. of Technology, Boston, Mass.; P. O. Box 416, Concord, Mass.	July 18, 1899
Smith, Wm. Stuart	U. S. N., U. S. Naval Station, Cavite, P. I.	July 26, 1900
Snyder, Nathaniel Marion,	County Surveyor for Scotts Bluff Co., Gering, Nebraska.	Nov. 23, 1900
Somellera, Gabriel F.	Partner, Salcedo & Co., Apartado 115, Mexico City, Mex.	April 25, 1900
Sowers, David W.	Sup't Buffalo Branch, New York Electric Vehicle Transportation Co., 240 W. Utica, St., residence, 67 W. North St., Buffalo N. Y.	July 18, 1899
Sparks, Chas. Pratt	Chief Engineer, The County of London Electric Lighting Co., Surrey, England.	Mar. 22, 1901
Spencer, Paul	Inspector of Electric Plants, United Gas Improvement Co., Broad and Arch Sts., Philadelphia, Pa.	Nov. 30, 1897
Spencer, Theodore	With Bell Telephone Co., N.E. Cor. 11th and Filbert Sts., Philadelphia, Pa.	Mar. 21, 1893
Sperling, R. H.	Assistant Engineer, British Columbia Electric Railway Co., Ltd., Victoria, B. C.	Nov. 23, 1898
Spiese, F. P.	Secretary, Treasurer and Manager the Edison Electric Illuminating Co., Tamaqua, Penn.	July 26, 1900
Squier, George O. Capt., *Ph.D.*	U. S. Signal Corps, c/o Chief Signal Officer, Div. of the Pacific, Manila, P. I.	May 19, 1891
Stahl, Th.	Mining Engineer for Messrs. Schneider & Co., Grenoble, France.	Nov. 15, 1892
Stakes, D. Franklin	Electrical Expert and Salesman, c/o. Siemens-Halske Electric Co., of America, 1500 Land Title Bldg. Philadelphia, Pa.	Jan. 20, 1897
Stanton, Chas. H.	With C. H. & H. Stanton Electrical Contractors, 1517 Walnut St.; residence, 134 S. 3d St., Philadelphia, Pa.	Mar. 20, 1895
Steele, Walter D.	Electrical Engineer, with Westinghouse, Church, Kerr & Co., 26 Cortlandt St.; residence, 31 West 32nd St., New York.	April 25, 1900
Stern, Philip Kossuth	Practicing Electrical and Mechanical Engineering, 130 Fulton St., N. Y.	Nov. 23, 1900
Stewart, John Bruce	Superintendent, Electric Plant, Virginia Hot Springs Co., Hot Springs, Va.	Aug. 23, 1899
Stewart, W. M.	District Inspector, New York Telephone Co., 30 Gold St., New York City.	Mar. 25, 1896
Stine, Wilbur M.	Professor of Engineering. Swarthmore College, Swarthmore, Pa.	May 15, 1894

Name.	Address.	Date of Election.
Stitzer, Arthur Bowers,	Draughtsman, Union Traction Co.; residence. 1909 N. Camac St., Philadelphia, Pa.	Oct. 24, 1900
Stockbridge, Geo. H. [Life Member.]	Patent Attorney, 120 Broadway; residence, 2514 11th Ave., near 187th St., New York City.	May 24, 1887
Stone, Charles A.	With Firm of Stone & Webster, 93 Federal St., Boston, Mass.	May 19, 1891
Stone, Joseph P.	c/o C. H. Stone, Room 1233, 156 Fifth Avenue, New York City.	Dec. 18, 1895
Storer, Norman W.	Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg; residence, Edgewood, Park, Pa.	Dec. 18, 1895
Stout, Joseph Suydam, Jr.	Inspector, Edison Electric Illuminating Co.; 55 Duane St., residence, 35 East 67th St., New York City.	Nov. 22, 1899
Straus, Theodore E.	Electrical Engineer, 13 W. Pratt St., residence, 1213 Linden Avenue. Baltimore, Md.	Nov. 18, 1896
Strauss, Herman A.	Electrical Engineer, Electrical Construction Dept. Manhattan Railway Co., 32 Park Place; residence, 188 St. Nicholas Ave., New York City.	Oct. 17, 1894
Strong, James Remsen	President, The Tucker Electric Construction Co., 35 South William St., N. Y; residence, Short Hills, N. J.	Mar. 22, 1901
Stuart, Harve R.	Electrical Engineer, with W. E. & M. Co.; residence, 524 Wallace Ave., Wilkinsburg, Pa.	Jan. 25, 1901
Sturdevant, Chas. Ralph	Assistant Professor of Electrical Engineering, Kentucky State College, Lexington, Ky.	May 16, 1899
Sturtevant, Charles L.	Patent Attorney, Atlantic Building, Washington, D. C.	Dec. 20, 1893
Stutz, Chas. C.	Master Mechanic, Pitttsburgh Plate Glass Co., Ford City, Pa.	Mar. 28, 1900
Summers, Leland L.	Electrical Engineer, 441 The Rookery, Chicago, Ill.	Feb. 16, 1892
Swann, John Joseph	The Ingersoll-Sergeant Drill Co., 26 Cortlandt St., New York City.	Jan. 26, 1898
Swenson, Bernard Victor	Assistant Professor of Electrical Engineering, University of Wisconsin, 404 W. Mifflin St., Madison, Wis.	Feb. 27, 1895
Sweet, Henry N.	2nd Vice-President, residence, 449 Washington St., Bridgeport, Conn.	May 20, 1890
Swinton, Alan Archibald Campbell	Consulting Electrical Engineer, 66 Victoria St., London S. W. England.	Mar. 22, 1901

Name.	Address.	Date of Election.
Swoope, C. Walton	Instructor, Electrical Engineering, Spring Garden Institute; residence, 12 North 38th St., Philadelphia, Pa.	Jan. 26, 1898
Swope, Gerard	Electrical Engineer, Mercantile Electric Co., 810 Spruce St., St. Louis, Mo.	Apr. 26, 1899
Sykes, Henry H.	Chief Engineer, Bell Telephone Co., of Mo., Telephone Bldg., St. Louis, Mo.	Oct. 18, 1893
Tachihara, Jin	Electrical Engineer, Mining Dep't, Mitsu Bishi Co., Tokyo, Japan.	Jan. 26, 1898
Tait, Frank M.	Superintendent, The Somerset Lighting Co., Somerville, N. J.	Sept. 19, 1894
Tapley, Walter H.	Electrician in Government Printing Office, care of Public Printer, Washington, D. C.	Oct. 25, 1892
Taylor, Irving A.	McCord and Seminary Sts., Montreal, P. Q.	May 17, 1898
Taylor, Jeremy F.	Electrician, Detroit Copper Company, Morenci, Arizona.	Dec. 27, 1899
Temple, William Chase	Consulting Engineer, Bank of Commerce Bldg., residence, 1090 Shady Ave., Pittsburg, Pa.	May 3, 1887
Tesla, Nikola	Electrical Engineer and Inventor, 46 E. Houston St., New York City.	June 5, 1888
Thayer, George Langstaff, *M. E.*,	Electrical Engineer, Oregon Short Line R. R. Co., Geneva, Ind.	Aug. 5, 1896
Thomas, John Williams	Construction Engineer, Electric Storage Battery Co., Hokendauqua, Pa.	Mar. 22, 1901
Thomas, Percy Holbrook,	Electrical Engineering Department, Westinghouse E. & M. Company, Pittsburg, Pa.	Oct. 24, 1900
Thomas, Robert McKean, *E. E.*	Member of the firm of Thomas & Betts, 141 Broadway; residence, 135 Madison Ave., New York City.	April 22, 1896
Thompson, Alfred J.	Manager, Electrical Dep't. Krajewski-Pesant Company, O'Reilly 15, Havana, Cuba.	Jan. 25, 1899
Thompson, Ermine John	In Testing Rooms Stanley Electric M'f'g. Co., 166 Union St., Pittsfield, Mass.	Jan. 25, 1901
Thompson, John West	c/o Cia Industrial de Guadalajara, Box 174, Guadalajara, Mexico.	Sept. 28, 1898
Thompson, Milton T.	Constructing Engineer, Mexican General Electric Co., Apartado 403, Mexico City, Mexico.	Jan. 24, 1900
Thompson, Silvanus P.	Morland, Chislett Road, West Hampstead, London, N. W., England.	Oct. 27, 1897

Name.	Address.	Date of Election.
THOMPSON, THOS. PERRIN	Master Electrician, Construction Dept. Norfolk Navy Yard, Portsmouth, Va.	Jan. 25, 1899
THOMPSON, WARREN RAY,	Assistant in Electrical Engineering Department, J. G. White & Company, 22a College Hill, Cannon St., London, England	Oct. 24, 1900
THOMSON, CLARENCE	Examiner, The Patent Office, Ottawa, Canada.	May 15, 1900
THOMSON, GEO. ANDROS	Special Agent, The Adams-Bagnall Electric Co , 136 Liberty St., New York; residence, Somerville, N. J.	Mar. 22, 1901
THORDARSON, CHESTER H.	Manufacturing Electrican, 128 LaSalle Ave.; residence, 6415 Lexington Ave., Chicago, Ill.	Dec. 18, 1895
THORNTON KENNETH BUCHANAN	Superintendent Line Department, The Royal Electric Co., residence, 840 Dorchester St. Montreal, P. Q.	Apr. 26, 1901
THURBER HOWARD F.	General Superintendent, New York Telephone Co., 18 Cortlandt Street, New York City; residence, 49 Sidney Place, Brooklyn, N. Y.	Mar. 25, 1896
TIDD, GEO. N.	Electrical Engineer and Manager, Beacon Light Co., Chester, Pa.	July 26, 1900
TINGLEY, E M	Westinghouse Elec. & M'f'g. Co.; residence, Amber Club, Pittsburg, Pa.	July 12, 1900
TOERRING, C. J.	C. J. Toerring Co., 1035 Ridge Ave., Philadelphia, Pa.	April 18, 1894
TOLMAN, CLARENCE M,	Electrical Engineer, Deep Leads Transmission Co., Melbourne, Victoria.	April 27, 1898
TORCHIO, PHILIPPO	Engineering Dep't, The Edison Elec. Illuminating Co., 53 Duane Street, New York City.	June 27, 1895
TOWER, GEORGE A.	V. P. Tower, Binford Electric and M'f'g. Co., 704 E. Main St., residence, 1414 Grove Ave., Richmond, Va.	May 15, 1894
TOWN, FREDERICK E.	Civil and Electrical Engineer. Supervising Architect's Office, Treasury Department, Washington, D. C.	May 15, 1900
TOWNLEY, CALVERT	Manager, Boston Office Westinghouse Electric and M'f'g. Co., 53 State St., Boston, Mass.	Feb. 28, 1901
TOWNSEND, HENRY C.	Attorney and Expert in Electrical Cases, 141 Broadway: residence, 354 W. 123d St., New York City.	July 10, 1888
TOWNSEND, FITZHUGH	Electrical Engineer, 116th Street and Amsterdam Ave.; residence, Union Club, Fifth Ave. and 21st St., New York City.	Jan. 20, 1897
TREADWELL, AUGUSTUS, JR.	*E. E.*, 100 Broadway, New York City; residence, 488 3d St., Brooklyn, N. Y.	Feb. 21, 1894

Name.	Address.	Date of Election.
Tripier, Henri	Counsel and Technical Engineer, of the Compagnie des Transports Electriques de l'Exposition. Paris, France; residence, 17 rue Caralloti, Paris, France.	Sept. 28, 1898
Trott, A. H. Hardy [Life Member.]	Beer, near Axminster, Devonshire, Eng.	Jan. 20, 1891
Trudeau, J. A. G.	329 Kent Street, Ottawa, Canada.	May 15, 1900
Truesdell, Arthur E.	50 Brenton Terrace, Pittsfield, Mass.	Feb. 15, 1899
Turnbull, Wallace Rupert.	Foreman of Experimental Room, General Electric Lamp Works; residence, 29 S. Arlington Ave., East Orange, New Jersey.	May 17, 1898
Tyng, Francis E.	Manager, Eastern Engineering Co., 164 W. 27th St., New York; residence. Cranford, N.J.	Dec. 28, 1898
Vail, Theo. N.	26 Cortlandt St., New York City.	April 15, 1884
Van Buren, Gurdon C.	Electrical Expert, with Federal Instrument Co., 82 State St., Albany, N. Y.	Oct. 25, 1892
Vandegrift, James A.	Treasurer and Manager, The Colorado Lamp Co., 2051 California St., Denver, Col.	Nov. 24, 1891
Vanderveen, Anthony R.	Machinist, The South India Railway Co., Holland Road, Negapatam, India.	Jan. 9, 1901
Van Deventer, Christopher	200 Equitable Building, Boston.	Feb. 17, 1897
Van Vleet, Roy Mitchell	Student. Westinghouse Electric and M'f'g Co., Edgewood Park, Pa.; residence, Port Huron, Mich.	Mar. 22, 1901
Van Wyck, Philip V. R., Jr.	New York Telephone Co., 15 Dey St.; residence, Plainfield, N. J.	April 21, 1891
Varney, Frank H.	Station Foreman San Francisco Gas and Electric Co., 2912 Mission St., San Francisco, Cala.	July 26, 1900
Varney, William Wesley	City Commissioner of Baltimore, office, City Hall; residence 712 N. Carey St., Baltimore, Md.	Nov. 21, 1894
Venable, Capt. Wm. Mayo	The National Contracting Co., 70 Kilby St., Boston, Mass.	Nov 30, 1897
Viehe, J. S.	Westinghouse Electric and Mfg. Co., Pittsburg. Pa.	May 15, 1900
Vinten, Ernest Stiles	Foreman Knob. Dept. Sargent Co.; residence, 89 Pearl St., New Haven, Conn.	April 27, 1898
Voit, Dr. Ernst	Professor of Electricity, Technical University, Schwanthalerstrasse, Munchen, Germany.	Mar. 21, 1894
Vreeland, F. K.	Ass't Engineer, Crocker-Wheeler Co., Ampere, N. J.	Oct. 26, 1898
Wagner, Herbert A.	Gen. Supt., Missouri, Edison Electric Co., and also with Wagner Electric Mfg. Co., 415 Locust St., St. Louis, Mo.	Sept. 28, 1898

Name.	Address.	Date of Election.
WALKEM, GEORGE ALEXANDER,	Electrical and Mechanical Engineer, P. O. Box 595, Vancouver, B. C.	Nov. 23, 1900
WALLACE, CHAS. F.	Engineer, Stone and Webster, 93 Federal St., Boston; residence, Wellesley Hills, Mass.	Nov. 18, 1896
WALLACE, WILLIAM	The Portland, Washington, D. C.	April 15, 1884
WALLAU, HERMAN L.	Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg. Hotel Seger, Turtle Creek, Pa.	May 15, 1900
WALLER, CHAS. WAITE	Sales Agent, General Electric Co., Claus Spreckels B'ld'g, San Francisco, Cal.	Aug. 23, 1899
WALMSLEY, WALTER NEWBOLD,	1002 Harrison Bldg., Philadelphia, Pa.	Oct. 24, 1900
WARNER, CHAS. H.	Consulting Electrical Engineer, 764 Rock St., Fall River, Mass.	Dec. 20, 1893
WARREN, ALDRED KENNEDY	Electrical Engineer, 120 Liberty St., New York; residence, 114 E. 17th St., New York City.	Nov. 20, 1895
WASON, CHAS. W.	President and Purchasing Agent, Cleveland, Painesville and Eastern R. R., Purchasing Agent. Akron, Bedford and Cleveland R. R., 616 Garfield Bldg., Cleveland, O.	May 19, 1891
WATERMAN, MARCUS B.	Assistant Electrician, Consolidated Telegraph and Electrical Subway Co., 55 Duane St., New York City; residence, 177 Lefferts Place, Brooklyn, N. Y.	Feb. 15, 1896
WATERS, EDWARD G.	General Electric Co., 44 Broad St., New York City.	Mar. 18, 1890
WEBB, HENRY STORRS [Life Member.]	International Correspondence Schools; residence, 225 Jefferson Avenue, Scranton, Pa.	Nov. 20, 1895
WEBB, HOWARD SCOTT	Professor of Electrical Engineering, University of Maine, Orono, Maine.	Oct. 24, 1900
WEBBER, CHARLES EDMOND	Major General, *C. B.* (ret.) *R E.* Past President and Member of Council, Institution of Electrical Engineers, 17 Egerton Gardens, London, England.	Jan. 9, 1901
WEBSTER, EDWIN S	Firm of Stone & Webster, 93 Federal St., Boston, Mass.	April 21, 1891
WELLES, FRANCIS R.	Manufacturer, 46 Avenue de Breteuil, Paris, France.	Sept. 6, 1887
WELLS, WALTER FARRINGTON	Supt 3rd Dist., Edison Electric Illuminating Co., 55 Duane St., residence, 69 East 92d St., New York, N. Y.	Apr. 26, 1899
WEST, JULIUS HENRIK	Engineer, Handjery St., 58 Friedenau, Berlin, Germany.	Sept. 20, 1893

Name.	Address.	Date of Election.
WESTON, SYDNEY F.	Assistant Engineer, Waldorf-Astoria Hotel; residence, 330 W. 33d St., New York City.	July 12, 1900
WHEILDON, LOUIS B.	Contractor and Expert, 1010 Exchange Building, Boston, Mass.	Oct. 24, 1900
WHITAKER, S. EDGAR	Superintendent and General Manager of the Portland and Yarmouth Electric Railway Co., 440 Congress St., residence, 221 Cumberland St., Portland, Me.	Aug. 5, 1896
WHITE, CHAS. G.	Public Schools Sup't, and Instructor in Physics and Chemistry, Lake Linden, Mich.	Sept. 23, 1896
WHITEHEAD, JOHN B., JR.	Associate in Applied Electricity, Johns-Hopkins University, Baltimore, Md.	Oct. 24, 1900
WHITING, ALLEN H.	Assistant Engineer, Riker Electric Vehicle Co., Elizabethport, N. J. residence, 320 Lexington Ave., New York City.	Nov. 18, 1896
WHITING, S. E.	Assistant in Electrical Dep't., Harvard University; residence, 11 Ware St., Cambridge, Mass.	May 16, 1899
WHITMORE, W. G.	Electrical Engineer, General Electric Co., Edison Building, Box 3067, New York City.	Mar. 18, 1890
WHITNEY, CLINTON EUGENE	Electrical and Mechanical Engineer, 61 W. 114th St., New York City.	Nov. 22, 1899
WHITNEY, HENRY M. [Life Member.]	95 Milk St., Boston, Mass.	July 12, 1887
WHITTED, THOS. BYRD	District Engineer, The General Electric Co., Denver, Col.	Mar. 22, 1899
WIDDICOMBE, ROBERT A.	Engineer, Western Electric Co.: residence, 1653 Roscoe St., Chicago, Ill.	Apr. 26, 1899
WIEDERHOLD, OSCAR	Supt. Natural Light Supply Co., 90 Orange St., residence, 14 Grace St., Bloomfield, N. J.	Aug. 13, 1897
WIESELGREEN, CARL EMIL	Allgemeine Electricitats Gesellschaft, Brunnenstrasse, Berlin, Ger.	Oct. 24, 1900
WIGHTMAN, MERLE J.	Electrical Engineer, 50 Broadway, New York City.	Mar. 5, 1889
WILEY, GEO. LOURIE	Manager, Standard Underground Cable Co., 56 Liberty St., New York, residence, Arlington, N. J.	Feb. 28, 1900
WILEY, WM. H.	Scientific Expert, 43 E. 19th St., New York City.	Feb. 7, 1888
WILKES, C. M.,	Engineer, D. H. Burnham & Co., 1142 The Rookery, Chicago, Ill.	Nov. 22, 1899
WILLIAMS, ARTHUR	General Inspector, The Edison Electric Illuminating Co., of New York; residence, 155 Linden Boulevard, Brooklyn, N. Y.	June 23, 1897

Name.	Address.	Date of Election
Williams, Charles Jr.	Electrician, 1 Arlington Street, East Somerville, Mass.	April 15, 1884
Williams, Geo. Henry	Lulworth, St. Andrews Park, Bristol, England.	Oct. 27, 1897
Williams, William Henry	Professor of Mechanical and Electrical Engineering. Montana State College, Bozeman, Mont.	Sept. 28, 1898
Wilson, Chester P.	Chief Engineer, The Milwaukee Electric Railway and Light Co., 451 Broadway, Milwaukee, Wis.	Sep. 25, 1895
Wilson, Howard S.	Superintendent Puebla Electric Light Co., Puebla, Mexico.	Aug. 23, 1899
Wilson, Robert M.	Faculty of Applied Science, McGill University; residence, 23 Seymour Ave., Montreal, P. Q.	Jan. 25, 1899
Winand, Paul A. N.	Engineer and Supt., Schleicher, Schumm & Co., 3200 Arch St., Philadelphia, Pa.	June 20, 1894
Winchester, Samuel B.	Superintendent Electrical Department, of the Holyoke Water Power Co., 5 Laurel St., Holyoke, Mass.	May 15, 1894
Winfield, James H.	Sup't Eastern Division, Nova Scotia Telephone, Ltd., Halifax, N. S.	May 17, 1898
Winslow, I. E.	The General Traction Company, Ltd., 35 Parliament Street, Westminster, London, Eng.	Nov. 12, 1889
Wintringham, J. P.	Theorist, 36 Pine St., Cable address, "Atlantic Scrip," New York City, and 153 Henry St., Brooklyn, N.Y.	May 7, 1889
Wirt, Herbert C.	Engineer, Supply Department, General Electric Co., Schenectady, N. Y.	June 26, 1891
Wise, John Shreeve, Jr.,	Electrician The Pa. Mfg. Light and Power Co.; residence, 2023 Mt. Vernon St., Philadelphia, Pa.	Feb. 15, 1899
Wolf, Lee H.	Contracting and Engineering, Honolulu, H. I.	Oct. 24, 1900
Wolff, Frank A. Jr.,	Professor of Physics and Electrical Engineering, Corcoran Scientific School. Columbian University, and in office U. S. Standard Weights and Measures. Washington, D. C.	Dec. 27, 1899
Wood, Arthur Bryant	321 Summit Ave., Schenectady, N.Y.	Jan. 9, 1901
Woodbridge, J. E.	Railway Engineering Department, General Electric Co., Schenectady, N. Y.	Oct. 26, 1898
Woodward, Wm. Carpenter	Electrical Engineer, Narragansett Electric Lighting Co., 60 Weybosset St., residence, 5 Charles Field St, Providence, R. I.	Nov. 18, 1896

Name.	Address.	Date of Election
Woodworth, Geo. K	Assistant Examiner, U. S. Patent Office; residence, 1424 S St., N. W., Washington, D. C.	Feb. 17, 1897
Woodworth, Philip Bell,	Professor of Electrical Engineering, Lewis Institute, Chicago; residence, 5808 Ohio St., Austin, Ill.	July 12, 1900
Woolf, Albert E.	Electrician and Inventor, The Electrozone Co , 415 Lexington Ave., New York City.	Sept. 16, 1890
Worswick, A. E.	Vice-President and Resident Engineer F. C. D., 3rd Calla de las Artes, Mexico City.	Sept. 20, 1893
Wray, J. Glen	Superintendent of Maintenance, Chicago Telephone Co., 203 Washington St., Chicago, Ill.	Sept. 20, 1893
Yarnall, Vernon H.	Eastern Manager McRoy Clay Works, 302 Broadway, Room 907, New York City.	May 16, 1893
Young, Charles I.	Electrical Engineer, Westinghouse Elec. & Mfg. Co., 120 Broadway, New York City.	June 27, 1895
Yslas, Carlos	Electrical Engineer and General Manager, Compania Telefonica Nacional, Jalapa, Ver. Mexico.	Nov. 18, 1896
Zabel, Max W.	Draughtsman and Student of Patent Law with John A. Brown & Cragg, 1450 Manadnock Bg., residence, 454 North Ave., Chicago, Ill.	Jan. 24, 1900
Zahm, A. Wilford	Electrical Engineer and Supt., Manhattan Light, Heat and Power Co., Manhattan Building, St. Paul, Minn.	Nov. 23, 1898
Zalinski, Edmund L.	Captain of Artillery, U. S. A., (retired), The Century, 7 West 43d St., New York City.	May 17, 188
Zani, Arnaldo P.	Electrical Engineer, Thomson-Houston Co., Piazza Cartello 5, Milano, Italy.	July 12, 1900
Zapata, J. M.	Constructing Engineer, The Mexican General Electric Co., Apartado 403, Mexico City.	Feb. 28, 1900
	Associate Members, - - - - .	880

(13)

OFFICIAL STENOGRAPHER

Ryan, Richard W., Room 178, Post Office Building, Telephone, 2787 Cortlandt. Residence, 125 W. 80th St., New York City.

SUMMARY.

Honorary Members, - - - - - - - - -	2
Members, - - - - - - - - - - - -	387
Associate Members, - - - - - - - - -	880
Total - - - -	1269

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

GEOGRAPHICAL DISTRIBUTION OF MEMBERSHIP.

(*Revised to May 15th, 1901.*)

NORTH AMERICA.

UNITED STATES.

ALABAMA.

Birmingham.—Harris, G. H.
Mobile.—Shaffner, S. C.
Montgomery.—Jones, H. C.

ARIZONA.

Morenci, Taylor, J. F.

ARKANSAS.

Fayetteville.—Gladson, W. N.

CALIFORNIA.

Bakersfield.—Bowie, A. J. Jr.

Berkeley.—

Babson, A. C.
Cory, Prof. C. L.
Le Conte, Joseph N.
Lynn, W. A.
Mortimer, Jas. D. 5

Bodie.—Downing, P. M.
Long Beach.—Griffes, E. V.
Haywards.—Clement, L. M.
Jackson.—Fry, D. H.

Marysville.—

Boyd, J. D.
Theberath, T. E. 2

Nevada City.—Hancock, L. M.

Oakland.—

Gaytes, Herbert, 395 Vernon St.
Holberton, G. C., Gas Light & Heat Co. 2

Oroville, Montague, R. L.
Riverside.—Henderson, H. B.

Sacramento.—

Crowell, Robinson
Hutton, C. W. 2

San Francisco.

Allen, W. H., 331 Pine St.
Barbour, Fred F., Claus Spreckels Bg.
Broili, Frank, 154 Hickory Ave.
Daggett, R. B., 42 Nevada Block.
Foster, S. L., Market & Valencia.
Glass, Louis Telephone Bldg.
Greenwood, F. A., 409 Market St.
Hanscom, W. W., 612 O'Farrell St.
Henry, G. J., Jr., 127 Main St.
Hewitt, Wm. R., 9 Brenham Place
Hitzeroth, L. D., 229 Stevenson St.
Hunt, A. M., 331 Pine St.
Lee, F. V. T., 33 New Montgomery
Lightbipe, Jas. A., Claus Spreckels Bg.
Low, George P., 320 California St.
Martin, John, 33 New Montgomery
Masson, R. S., 327 Market St.
Meredith, Wynn, 331 Pine St.
Molera, E. J. 2025 Sacramento St.
Napthaly, S. L., 500 Parrott B'ld'g
Poole, C. O., Crocker B'ld'g.
Ridley, A. E. B., 598 Parrott B'ld'g
Russell, H. A., 302 Laurel St.
Sharpe, E. C., 25 Fremont St.
Smith, F. E., 183 Jessie St.
Varney, F. H., 2912 Mission St.
Waller, C. W., Claus Spreckels B'ld'g 27

Stanford University.—

Baum, F. G.
Copeland, C. A. 2

Stockton.—Adams, F. P.

COLORADO.

Aspen.—Doolittle, Clarence E.
Boulder.—Ford, A. H.
Canon City.—Wilcox, N. T.

Denver.

Searing, L., 924 Washington Ave.
Sethman, G. H., 2305 Boulevard F.
Stearns, J. W. Jr., Mountain Elec. Co.
Vandegrift, J. A., 2051 California St.
Whitted, T. B., Kittredge B'ld'g. 5

Silverton.—Holt, M.B.
Telluride.—Nunn, Paul N

CONNECTICUT.

Ansonia.—Grower, George. G.

Bridgeport.

Crocker. E. C., 29 Harriet
Powell. P. H., 530 State
Sweet, H. N., 449 Washington Ave.
3

Deep River.—Selden, R. L. Jr.

Hartford.

Condict, G. H., Col. & Elec.Vehicle Co.
Corson, W. R. C., 127 Oxford St.
Robb, Prof. Wm. L., Trinity College.
Sachs, Jos., The Johns-Pratt Co.
Strong, F. G., Box 959.
Waring, John, 31 Russ St.
6

Middletown.

Raub, C. B.
Rosa, E. B. 2

New London.—Storrs, H. A.

New Haven.

Boynton, E. C., N.Y.N.H. & H.R.R.
Heft, N. H. " " "
Vinton, E. S., Sargent & Co.
3

South Norwalk.—Winchester, A.E.
South Manchester.—Adams, J. L.
Windsor.—Heath, Harry E.

DELAWARE.

Wilmington.—Van Trump, C. R.
Wilm City Elec. Co.

DISTRICT OF COLUMBIA.

Washington.

Allen, W. C., District B'ld'g
Berliner, Emile, Columbia Road
Betts, Philander, Bur. Yards & Docks.
Bliss, L D., 614 12th St.
Chappell,W.E., U.S.S.Chicago,U.S.N.
Crosby, O. T., 1417 G St.
Dieterich, F. G., 602 F St.
Fessenden, R. A., Weather Bureau.
Freeman, Frank L., 931 F St.
Hopkins, N.M., Columbian University.
Ives, E. B., c/o War Dept.
Jackson, W. S., 325 Spruce St.
Lyons, Joseph, 908 G St.
Mauro, Philip. 620 F St.
Maynard, G. C., Smithsonian Inst.
Morgan, C. H., Patent Office.
Robinson, A. L., Southern R'w'y Co.
Roller, J. E., U. S. Navy Dept.
Saylor, F. A., U. S. S., Chicago.
Shea, D. W., Catholic University
Sturtevant, Charles L., Atlantic B'ldg.
Tapley, W. H., Gov. Printing Office

Washington.—Continued.

Town, F. E., Treasury Dep't.
Wallace, Wm., The Portland.
Wolff, F. A. Jr., Columbian Univ'y.
Woodworth, G. K., 1424 S St., N. W.
26

FLORIDA

Jacksonville.—Hammatt, C. S.

GEORGIA.

Atlanta.

Bryan, R. R., 1018 Prudential B'ld'g.
Burkett, C. W., 321 Austell Building.
Schoen, A. M., 339 Equitable B'ld'g.
Wotton, J. A., Box 543. 4

Augusta.

Edwards, Jas. P.
Moore, W. E.
2

Columbus.—Boileau, W. E.
Macon.—Nyhan, J. T.
Savannah.—Nunn, Richard J., *M.D.*

IDAHO.

Dewey.—Phillips, L. A.

ILLINOIS.

Alton.

Porter, J. F., 205 Market St.

Chicago.

Abbott, Arthur V., 203 Washington St.
Armstrong, C. G., Fisher B'ld'g
Arnold, Bion J., 1541 Marquette B'ld'g
Badt, Lt. Francis B., 1504 Monadnock
Ball, W. D., 614 Rookery.
Barnett, C. P., 41st St. & Ashland Ave.
Barton, Enos M., 259 South Clinton St.
Boggs L. S., 1000 Isabella Bldg.
Brinckerhoff, H. M., 1001 Royal Insurance Bldg.
Brown, C. L., 1211 Monadnock B'ld'g
Crandall, Chester D., 259 S. Clinton St.
Crozier, A. B., 41st St. & Ashland Ave.
Damon, G. A., 1541 Marquette B'ld'g
de Khotinsky, A., 5526 Jefferson Ave.
Dommerque, F.J., Congress & Green Sts.
Dunbar, F. W., Congress & Green Sts.
Duncan, Thomas, Grant Works.
Eddy, H. C., Lees Building
Etheridge, Locke, 1001 Monadnock
Frantzen, Arthur, 225 Dearborn St.
Goltz, Wm., 1504 Monadnock B'ld'g
Hartwell. Arthur, 171 La Salle St.
Haskins, Clark C., 682a W. Adams St.
Haubrich, A. M., 1309 Ashland Block.
Hellick, C. G., 203 Washington St.
Hibbard, Angus S. 203 Washington St.
Huguet, C. K., 731 Jackson Boulevard

Chicago.—Continued.

Insull, Samuel, 139 Adams St.
Kinsley, Carl, 203 Washington St.
Knox, G. W., 2329 Magnolia Ave.
Kreidler, W. A., 510 Marquette B'ld'g
Lansingh, V. R., 259 S. Clinton St.
Lyman, James, Monadnock B'ld'g
Macomber, I. J., Armour Inst.
Mayer, G. M., 1401 Monadnock B'ld'g.
Miller, K. B., Congress & Green Sts.
Morehead, J. M., 157 Michigan Ave.
Neiler, S. G., 1409 Manhattan B'ld'g
Neurath, M.M., 1444 Monadnock B'ld'g
O'Connell, J. J., 203 Washington St.
Pen Dell, C. W., 109 S. Pine Ave., Austin Sta.
Pierce, R. H., 1409 Manhattan B'ld'g
Ray, W. D , 1626 Marquette B'ld'g.
Reichmann, F., University of Chicago.
Richardson, R. E., 1409 Manhattan Bg.
Rideout, A. C., 101 Randolph St.
Schweitzer, E. O., 139 Adams St.
Searles, A. L., Marquette B'ld'g
Summers, Leland L., 441 Rookery
Thordarsson, C. H., 128 LaSalle Ave.
Wait, Henry H., 259 So. Clinton St.
Warner, E. P., 259 So. Clinton St.
Widdicombe, R. A., 259 S. Clinton St.
Wilkes, C. M., 1142 The Rookery
Woodworth, P. B., Lewis Inst.
Wray, J. G., 203 Washington St.
Zabel, M. W. 1450 Monadnock B'ld'g.
56

Elmwood.—Phelps, W. J.

Maywood.—Kennedy, A. P.

Oak Park.—

Bentley, M. H., 221 N. Scoville Ave.

Peoria—Gutmann, L.

Quincy.—Chubbuck, H. E.

Urbana.

Aldrich, W. S.
Browne, W. H., Jr.
Esty, William.
3

Winnetka.—Herdman, F. E.

INDIANA.

Anderson.—Richey, A. S.

Fort Wayne.

Barnes, Edw. A. Ft Wayne Electric Co.
Crawford, D. F., P. R. R.
Hadley, A. L., Ft. Wayne Elec. Works
Hunting, F. S., 325 W. Washington St.
4

Indianapolis.—

Green, E. C., 1710 Prospect St.
Marsh, H. B., 8 West Market St.
2

Geneva.—

MacFadden, C. K.
Thayer, G. L., 2

Lafayette.

Esterline, J. W., Purdue University.
Marshall, Cloyd
Goldsborough, W. E., 113 South St.
Matthews, C. P., 168 Pierce St.
4

Terre Haute.

Balsley, Abe, 118 No. 9th St.

IOWA.

Ames.—Lanphear, B. S.

Fort Dodge.—Cunningham, E. R.

Montezuma.—Mortland, J. A.

KANSAS.

Topeka.—McVay, H. D.

Wichita.—Baker, A. O.

KENTUCKY.

Lexington.—Sturdevant, C. R.

Louisville.

Hubley, G. W., 8th and Greene Sts.
McLeod, Geo., 29th & High Sts. 2

LOUISIANA.

New Orleans.

Ayres, Brown, Tulane University.
Carroll, Leigh, 708 Union St.
Offutt, A., Und. Inspection Bur. 3

MAINE.

Lewiston.—Robinson, Almon

Orono.—Webb, Howard S.

Portland.

Mather, E. H.
Whitaker, S. E., 440 Congress St. 2

MARYLAND.

Annapolis.—Dodge, O. G.

Baltimore.

Brackett, B. B., 916 McCulloh St.
Browne, S. H., Md. Tel. B'ld'g
Ellard, John W., 506 Merchants B'k Bg.
Hall, Clayton C., 10 South St.
Holmes, G. R , 215 No. Calvert St.
Keilholtz, P. O., 330 No. Charles St.
McCay, H. K., 106 E. German St.
Morrison, J. Frank, 15 South St.
Schoolfield, F. R., 738 W. Fayette St.
Schwab, M. C. 1729 Madison Ave

Baltimore.—Continued.

Scott, J. B., 227 E. German St.
Straus, Theo., 13 W. Pratt St.
Varney, W. W., 712 N. Carey St.
Whitehead, J. B. Jr., John Hopk's Un.
Young, W. D., Roland Park 15

MASSACHUSETTS.

Amherst.—Barry, David
Andover.—Coleman, W. H.
Auburndale.—Blake, Francis

Boston.

Adams, A. D., Box 1377
Archer, G. F., 284 Marlboro St.
Bancroft, C. F., 14 Kilby St.
Blodgett, Geo. W., B. & A. R. R.
Blood, J. B., 22A Equitable B'ld'g
Brophy, Wm., 11 Wareham St.
Burleigh, Chas. B., 200 Summer St.
Cabot, F. E., 55 Kilby St.
Childs, A. E., 23 Centre St.
Codman, J. S., 31 Milk St.
Coffin, Chas. A., 180 Summer St.
Cross, Chas. R., Mass. Inst. Tech.
Davenport, Geo. W.., 183 Essex St.
Davis, P. W., Elec. Stor. Bat. Co.
Doolittle, Thos. B., 125 Milk St.
Edgar, C. L., 5 Head Place
Erickson, F. Wm., 71 Federal St.
Ford, Wm. S., Room 73, 125 Milk St.
Garratt, A. V., 61 Hampshire St.
Goddard, C. M., 55 Kilby St.
Greenleaf, L. S., 15 Oliver St.
Hamilton, Jas., 53 State St.
Hayes, Hammond V., 125 Milk St.
Herrick, Charles H., 3 Head Place
Hosmer, Sidney, Ames Building
Le Clear, Gifford, 15 Exchange St.
Lee, J. C., 125 Milk St.
Lockwood, Thomas D., 125 Milk St.
Mansfield, A. N., 125 Milk St.
Paine, Sidney B., 180 Summer St.
Puffer, Wm. L., Mass. Inst. of Tech.
Richards, C. W., 178 Devonshire St.
Robb, Russell, 93 Federal St.
Ross, Norman N., c/o General P. O.
Smith, W. L., Mass. Inst. of Tech.
Smith, F. B., 170 Summer St.
Spaulding, H. C., 410 Exchange B'ld'g.
Stearns, C. K., 93 Federal St.
Stone, Charles A., 93 Federal St.
Taintor, Giles, 125 Milk St.
Townley, C., 53 State St.
VanDeventer, C., 200 Equitable B'ld'g.
Venable, W. M., 70 Kilby St.
Wallace, C. F., 93 Federal St.
Webster, Edwin S., 93 Federal St.
Whieldon, L. B., 1010 Exchange Bldg.
Whitney, Henry M., 95 Milk St. 47

Brighton.—Baldwin, J. C. T.
Brookline.—Fleming, J. F.

Cambridge.

Adams, C. A., Jr., 13 Farrar St.
Ayer, Jas. I., Franklin & Sidney Sts.
Clark, W. E., 1400 Mass. Ave.
Whiting, S. E., 11 Ware St.
4

Cambridgeport.—Hopewell, C. F.

Danvers.—Hood, R. O.
East Saugus.—Fog, C. F.
East Somerville.—Williams C., Jr.
Fall River.—Warner, C. H.
Great Barrington.—Stanley, Wm.
Holyoke.—Winchester, S. B.
9 Laurel St.
Hudson.—Lawrence, W. G.
Jamaica Plain.—Balcome, H. A.
Lawrence.—Humphreys, C. J. R.

Lynn.

Boyer, E. E., Gen'l Electric Co.
Fish, Walter C., " "
Hopkins, N. S., " "
Lemp, H. Jr., " "
Thomson, Elihu, " "
6

Marblehead.—Graves, C. B.
Marlborough.—Doane, S. E.

Natick.

Appleyard, A. E.
Gale, H. B. 2

Newton Centre.—Bell, Louis

Pittsfield.

Bergenthal, V. W., Stanley Electric Co.
Chesney, C. C., " "
Heitmann, E. Jr., " "
Jackson, W. B. " "
Kelly, J. F., " "
Perrine, F. A. C., " "
Rushmore, D. B., " "
Thompson, E. J., " "
Truesdell, A. E., 50 Brenton Terrace.

Springfield. 9

Anderson, H. S., United E. L. Co.
Hyde, Jerome W., Wason Building 2

Worcester.

Haskins, W. E., Am. Steel & Wire Co.
Jones, F. R., Polytechnic Inst.
Latham, H. M., Am. Steel and Wire Co.
Smith, H. B., Polytechnic Inst.
4

MICHIGAN

Ann Arbor.—
Carhart, H. S.

Bay City.—Fitzhugh, W. H.

Detroit.
Blades, Harry H., 419 Cass Ave.
Dow Alex, 18 Washington Ave.
Field, H. G.,1203 Majestic B'ld'g
Jackson, E. D., 82 Beech St.
Livsey, J. H., 704 Chamber of Com.
Stewart, R. S., 440 Jefferson Ave. 6

Grand Rapids.—Cody, L. P., 9 So. Division St.

Lake Linden.—White, C. G.

Rochester.—Molé, H. E.

MINNESOTA.

Minneapolis.

Burch, E. P., 1210 Guaranty B'ld'g.
Flather, J. J., Univ. of Minn.
Kelsey, J. C., N. W. Tel. Ex. Co.
Pillsbury, C. L., Lumber Exchange.
Shephardson, G. D., Univ. of Minn.
Springer, F. W., Univ. of Minn. 6

St. Paul.

Gille, H. J., St. Paul Gas Light Co.
Simpson, J. M., Grass Twine Co.
Zahm, A. W., Manhattan B'ld'g 3

Willmar.—Johnson, A. C.

MISSISSIPPI.

University.—Anderson, D. S.

MISSOURI.

Columbia.—Shaw, H. B.

Kansas City.

Kent, J. M., M. T. High School.
Morgan, J. L., City Hall.
Weeks, E. R., 608 New Nelson B'ld'g.

St. Louis. 3

Durant, Geo. F., Telephone B'ld'g
Garrels, W. L., 3 Franklin Bk. Bldg.
Hessenbruch, G. S., 205 Union Station Terminal.
Humphrey, H.H., 1305 Chemical B'ld'g.
Klauder, R. H., 817 Wainwright Bldg.
Layman, W. A., 2017 Locust St.
Randall, J. E., 1912 Olive St.
Roper, D. W., 19th & Gratiot Sts.
Schlosser, F. G., 411 No. 11th St.
Schwedtmann, F., 2017 Locust St.
Swope, Gerard, 810 Spruce St.
Sykes, H. H., Telephone Building
Wagner, H. A., 415 Locust St. 13

MONTANA.

Anaconda.—Magnus, B.

Bozeman.—Williams, W. H.

Canyon Ferry.—Gerry, M. H., Jr.,

Great Falls.—Morrow, John T.

NEBRASKA.

Gering.—Snyder, N. M.

Lincoln.—Brooks, Morgan.

Omaha.

Pearson, F. J., Woodmen Bldg.
Schurig, E. F., 306 City Hall 2

NEVADA.

Virginia City.—Fielding, Frank E.

NEW HAMPSHIRE.

Concord.—Albin, H. A.

Manchester.

Clough, A. L., Box 114
Smith, J. Brodie, 142 Merrimack St. 2

NEW JERSEY.

Ampere.

Archibald, E. M., Crocker-Wheeler Co.
Dowie, Horace, " "
Dunn, G. S., " "
Henshaw, F. V., " "
Vreeland, F. K., " "
Wheeler, S. S., " " 6

Arlington.—Keith, N. S.

Bayonne.—Chamberlain, J. C.

Bloomfield.—Rosenbusch, G.,
Wiederhold, O., 90 Orange St. 2

Bridgeton.—Smith, Oberlin

Camden.—
Harrington, Walter E.
Ross, T. W., 556 Federal St. 2

East Orange.
Jackson, F. E., 61 So. Grove St.
Turnbull, W. R., 29 So. Arlington Ave. 2

Elizabeth.

Diehl, Philip, Diehl M'f'g Co.
Bennett, E. H., Jr., Singer M'f'g Co.
Miller, H. S., Diehl M'f'g Co.
Riker, A. L., Riker Elec. Vehicle Co.
Whiting, A. H., " " 5

Garwood.—Fowler, Geo. W.

Harrison.

Howell, J. W.
Howell, Wilson S.
Marshall, J. T.
Page, A. D. 4

Hoboken.

Cuntz, Johannes H., 325 Hudson St.
Denton, J. E., Stevens Institute
Ganz, A. F., " "
Geyer, Wm. E., " "
Morton, Henry " "

5

Jersey City.

Ockershausen, H. A.
Rushmore, S. W., 24 Morris St.

2

Newark.

Bosch, Adam, Fire Alarm Telegraph.
Colby, Edward A., Lock Box 113
Farrand, Dudley, 207 Market St.
Hammer, E. W., 46 2d Ave.
Moore, D. McF., 52 Lawrence St.
Weston, Edward, 114 William St.

6

Orange.

Edison, Thomas A.
Upton, F. R.

2

Perth Amboy.

Brewster, W. S., 26 Washington St.
Prosser, H. A.

2

Plainfield.

McClurg, W. A., 207 Madison Ave.

Princeton.—Brackett, C. F.

Rahway.—Buys, Albert

Roselle.—Colvin, F. R.

Rutherford.

Petty, Walter M.
Schwabe, W. P.

2

Somerville.—Tait, F. M.

South Amboy.—Flack, J. Day

South Orange.—Delany, P. B.

Trenton.

Horn, H. J., 36 W. State St.
Newbury, F. J., Roeblings Co.
Roebling, F. W., Roeblings Co.

3

Westfield.

Foote, Thos. H.
Mansfield, R. H., Jr.

2

NEW MEXICO.

Mesilla Park.—Brady, F. W.

NEW YORK.

Albany.

Judson, W. P., State House.
McElroy, James F., 131 Lake Ave.
Miller, Wm. C., 3 South Hawk St.
Van Buren, Gurdon C., 82 State St.

4

Auburn.—Case, W. E.

Belmont.—Gorton, Charles

Bronxville.

Carpenter, C. E.
Leonard, H. Ward

2

Brooklyn.

Barstow, W. S., 360 Pearl St.
Benoliel, S. D., Adelphi College
Broich, Jos., 1622 8th Ave.
Chapman, A. W., 160 Hicks St.
Field, C. J. Church Lane & 37th St.
Holbrow, H. L., U. S. Navy Yard.
Gherardi, B. Jr., 81 Willoughby St.
Leitch, H. W., 373 Madison St.
Martin, F., U. S. Navy Yard.
Martin, J., " "
Mosscrop, W. A., 47 Brevoort Pl.
Ormsbee, A. F., 81 Willoughby St.
Peck, E. F., 187 Montague St.
Powelson, W. V. N., U. S. Navy Yard.
Reilly, John C., 81 Willoughby St.
Rice, A. L., Pratt Institute
Sargent, W. D., 81 Willoughby St.
See, A. B., 116 Front St.
Shaw, A. N., 116 Front St.
Sheldon, Samuel, Polytech. Institute.
Wolcott, T., 329 Clinton St.

21

Buffalo.

Gifford, C. E., Caton's College.
Haskins, C. H., 70 Linwood Ave.
Howe, W. K., Carroll and Wells Sts.
Huntley, C. R., 40 Court St.
McCarthy, E. D., 45 No. Division St.
Meadows, H. G., 109 White B'ld'g.
Offinger, M. H., 217 E Eagle St.
Perkins, Frank C., 126 Erie Co. Bank.
Pope, H. W., 14 W. Seneca St.
Ramsey, H. N., 32 Wells St.
Rustin, Henry, Pan Am. Exposition.
Sowers, D. W., 240 W. Utica St.

12

Elmira.

Uebelacker, C. F., Munic Improv'nt Co.
Wolverton, B. C., N.Y. & Pa. T. & T. Co.

2

Ithaca.

Bedell, Fred. Dr., Cornell University.
Hoxie, G L., 1192 Cascadilla Place.
Nichols,, E. L., Cornell University.
Ryan, H. J., " " 4

Larchmont.—Neilson, John

Lockport.—Kenan, W. R., Jr.

Mamaroneck.—Farnsworth, A. J.

New Brighton.—Libby, S. B.

Newburgh.—Hewitt, C. E.

New York City.

Abbott, Henry, 9 Maiden Lane
Adams. E. K., 455 Madison Ave.
Adler, A. A., 123 Liberty St
Agnew, C. R., 18 William St.
Albright, H. F., 57 Bethune St.
Alexander, Harry, 25 W. 33d St.
Allen, A. P., 15 Dey St.
Andrews. W. C. 120 Liberty St.
Anthony, W. A., Cooper Union
Ashley, F. M., 95 Liberty St.
Atkins. H. B., 22 William St.
Atwood, G. F., 463 West St.
Aylmer-Small, C S., Columbia Univ.
Baillard, E. V., Fox Building.
Baldwin, A. de V., 39 Cortlandt St.
Bangs, C. R. 15 Dey St.
Banks, W. C., 13 Laight St.
Baron, Max D., 25 W. 33rd St.
Batchelor, C., 52 Broadway.
Bates, F. C., 44 Broad St.
Bates, J. H., 57 Duane St.
Bates, P. A., 39 Cortlandt St.
Baylis, R. N., 99 Cedar St.
Beaumont, C. W , 45 Broadway.
Bell, O. A., 463 West St.
Bellman, J. J., 26 Cortlandt St.
Bennett, J. C., 44 Broad St.
Bethell, U. N., 15 Dey St.
Betts, H. D., 141 Broadway
Bijur, Jos., 210 Centre St.
Birdsall, E. T., 26 Cortlandt St.
Black, C. N., 149 Broadway.
Black, H. D., 39 Cortlandt
Blackall, F. S., 39 Cortlandt St.
Blake, Henry W., 120 Liberty St.
Blake, T. W., 410 Bleecker St.
Bliss. W. L., 128 Front St.
Bonynge, Paul, 141 Broadway.
Bogue, Chas. J., 206 Centre St.
Bohm, Ludwig K., 320 Broadway.
Bourne, Frank, 26 Cortlandt St.
Bradley, C. S., 44 Broad St.
Brixey, W. R., 203 Broadway.
Brown, Alfred S., 195 Broadway
Brown. J. Stanford, 1 Broadway
Brown, W. D., 61 Elm St.
Buckingham, Chas. L., 195 Broadway
Bunce, Theo. D. Jr., 239 E. 27th St.
Burdick, I. E., 95 Liberty St

New York City.—Continued.

Burnett, Douglass, 55 Duane St.
Burroughs, H. S., 20 Nassau St.
Burton, Paul G., 463 West St.
Byrns, R. A., 20 Broad St.
Caldwell, Edw., 150 Nassau St.
Canfield, M. E., 57 Bethune St.
Carichoff, E. R. 52 Broadway.
Carty, J. J., 15 Dey St.
Chandler, C. F., Columbia Univ.
Child, C. T., 13 Park Row.
Childs, S. W., 29 Broadway.
Clark, C. M., 42 E. 23d St.
Clark, Ernest P., 19th St. & 6th Ave.
Clark, F. G., 96th St. and 1st Ave.
Clark, Le Roy, Jr., 229 W. 28th St.
Clark, W. J., 44 Broad St.
Clarke, Charles L., 31 Nassau St.
Coho, H. B., 149 Broadway
Collett, S. D., 136 Liberty St.
Comstock, L. K., 137 Broadway.
Cornell, C. L., 136 Liberty St.
Cornell, J. B , 136 Liberty St.
Compton, A. G., 17 Lexington Ave.
Crane, W. F. D., 20 Broad St.
Criggal, J. E., 463 West St.
Crocker, Francis B., Columbia Univ.
Cushing, H. C., Jr., 39 Cortlandt St.
Cuttriss, Chas., 20 Broad St.
Damon, Geo. B., 12 West 31st St.
Davidson, E. C., 141 Broadway
Davis, Chas. H., 25 Broad St.
Davis, Joseph P., 113 W. 38th St.
Davis, Minor M., 253 Broadway
Decker, E. P., 26 Cortlandt St.
Dickerson. E. N., 141 Broadway
Doherty, H. L., 40 Wall St.
Doremus, C. A.. 59 W. 51st St.
Dressler, Chas. E., 17 Lexington Ave.
DuBois, Tuthill, 19 Park Place.
Duncan, J. D. E., 31 Nassau St.
Duncan, Louis, 71 Broadway
Dunn, C. E., 1029 Park Row B'ld'g.
Durant, Edward, Ward's Island.
Dyer. R. N., 31 Nassau St.
Edwards, C. V., 220 Broadway
Fliess, R. A., 201 W. 55th St.
Floy, Henry, 220 Broadway
Forbes, Francis, 32 Nassau St.
Ford, F. R., 149 Broadway
Frank, G. W., Jr., 29 Brodway
Gallatin, A. R., 58 W. 55th St.
Gibson, G. H., 220 Broadway
Goldmark, Chas. J., 66 New St.
Gordon, Reginald, Columbia Univ.
Gotshall, W. C., 46 5th Ave.
Granbery, J. H., 32 Park Place.
Griffen, J. D., 25 Broad St.
Griffin, E., 44 Broad St.
Guy, Geo. H., 120 Liberty St.
Hadaway W. S. Jr. 107 Liberty St.
Hadley, F. W., 26 CortlandtSt.
Hall, Edw. J., 15 Dey St.

New York City.—Continued.

Hall, F. A., 115 W. 47th St.
Hallberg, J. H., 572 First Ave.
Hamilton, Geo. A., 463 West St.
Hamerschlag, A. A., 41 Liberty St.
Hammer, W. J., 922 Havemeyer Bg.
Hanchett, Geo. T., 123 Liberty St.
Harding, H. McL. 20 Broad St.
Hathaway, J. D., Jr., 463 West St.
Hatzel, J. C., 114 Fifth Ave.
Hayes, Harry E., 22 Thames St.
Hedenberg, W. L., 136 Liberty St.
Henderson, Alex., 527 W. 34th St.
Herzog, Dr. F. Benedict, 51 W. 24th St.
Higgins, Edward E., 32 Waverly Place.
Hildburgh, W. L., Hotel Normandie
Hill, George 150 5th Ave.
Hill, G. Henry, 527 W. 34th St.
Hill, N. S. Jr., 100 William St.
Hoffman, B., 15 Dey St.
Holmes, Franklin S., 108 Fulton St.
Howson, Hubert, 38 Park Row
Hubbard, A. S., 25 W. 33d St.
Hubbard, W. C., 11 Broadway.
Hunt, A. L., 203 Broadway
Hutchinson, Cary T., 71 Broadway
Hyde, J. E. H., 120 Broadway.
Idell, Frank E., Havemeyer Building.
Insull, M. J., 572 1st Ave
Jaeger, C. L., 132 Mulberry St.
James, H. D., 71 Broadway.
Jannus, F., 141 Broadway
Jenks, W. J., 120 Broadway
Johnston, T. J., 66 Broadway.
Johnston, W. J., 95 Liberty St.
Jones, Francis W., 253 Broadway
Keefer, E. S., 463 West St.
Kennedy, J. J., 29 Broadway.
Ker, W. W., 36 Stuyvesant St.
King, V. C., Jr., 517 West St.
Kinsman, F. E., 26 Cortlandt St.
Knowles, E. R., 136 Libeyty St.
Knox, C. E., 76 William St.
Knudson, A. A., 32 Nassau St.
Lamb, Richard, 136 Liberty St.
Langton, Jno., 72 Trinity Pl.
Lanman, Wm. H., 120 Broadway
Lardner, H. A., 29 Broadway.
La Roche, F. A., 652 Hudson St.
Lawrence, W. H., 49 W. 26th St.
Ledoux, A. R., 99 John St.
Leeds, Norman, 463 West St.
Leslie, E. A., 57 Duane St.
Lieb, J. W., Jr., 57 Duane St.
Livingston, J. Jr., 13 Park Row
Lloyd, Robert McA., 100 Broadway
Loewenthal, M., 11 Broadway.
Louis, O. T., 340 E. 119th St.
Lowther, C. M., 36 Riverside Drive.
Lozier, R. T. E., 220 Broadway
Lundell, Robert, 527 W. 34th St.
Lundie, John, 52 Broadway
Lyford, O. S., Jr. 100 Broadway.
Lyman, C. W., 30 Broad St.

New York City.—Continued.

MacGregor, W. H., 136 Liberty St.
Mahoney, J. J., 44 Broad St.
Mailloux, C. O., 76 William St.
Marks, L. B., 689 Broadway
Martin T. Commerford, 120 Liberty St.
Marvin, H. N., 841 Broadway.
Maver, William . Jr., 120 Liberty St.
Mayer, M. M., 2369 2d Ave.
McClure, W. J., 259 W. 52d St.
McLain, R. C., 21 Park Row.
McLimont, A. W., 141 Broadway.
Merrill, E. A., 26 Cortlandt St.
Mershon, R. D., 621 Broadway
Meyer, Julius, 115 Broadway
Monrath, Gustave, 7 E. 42d St.
Mora, M. L.44 Broad St.
Morley, E. L., 114 5th Ave.
Moses, P. R., 35 Nassau St.
Mullin, E. H., 44 Broad St.
Murphy, J. McL., 116 Nassau St.
Muschenheim, F. A., 463 West St.
Nicholson, S. L., 120 Broadway.
Nimis, A. A., 1221 Lexington Ave.
Noll, Augustus, 8 E. 17th St.
Osterberg, Max, 11 Broadway
Paine, F. B. H., 120 Broadway
Parker, H. C., Columbia Univ.
Parmly, C. Howard, 17 Lexington Ave.
Parsell, H. V. Jr., 129 W. 31st St.
Pattison, Frank A. 141 Broadway
Pearson, F. S., 621 Broadway
Pedersen, F. M. 17 Lexington Ave.
Pfund, Richard, 601 W. 169th St.
Pickernell, F. A., 22 Thames St.
Poole, Cecil P., 120 Liberty St.
Pope, Ralph W., 26 Cortlandt St.
Porter, H. H., Jr., 31 Nassau St.
Price, C. W., 13 Park Row
Prince, J. L., 57 Duane St.
Proctor, T. L., 39 Cortlandt St.
Pupin, Michael I., Columbia Univ.
Rae, Frank B., 35 Broadway.
Reber, Samuel, Governor's Island.
Reckenzaun, F., 44 Pine St.
Reed, H. A., 420 E. 25th St.
Reed, H. D., 420 E. 25th St.
Reid, Thorburn, 136 Liberty St.
Rennard, J. C., 15 Dey St.
Rice, Calvin W., 55 Duane St.
Ries, E. E., 346 Broadway
Ripley, W. H., 24 Murray St.
Roberson, O. R., 195 Broadway
Robinson, F. G., 621 Broadway
Roller, F. W., 203 Broadway
Rosenbaum, Wm. A., Times B'd'g
Rosenberg, E. M., 138 W. 85th St.
Rouquette, W. F. B., 47 Dey St.
Ryerson, W. N., 146th St., & Lenox Ave.
Sanborn, F. N., 29 Wall St.
Sanderson, E. N., 31 Nassau St.
Sanville, H. F., 15 Cortlandt St.
Saxelby, F., 220 Broadway.
Scheffler, F. A., 9 Dey St.

New York City.—Continued.
Schreiter, Heinr., 20 Nassau St.,
Scudder, H. Jr., 21 E. 22d St.
Serrell, Lemuel Wm. 99 Cedar St.
Sever, Geo. F., Columbia Univer.
Simpson. A. B., 54 M. Lane
Sinclair, H. A., 35 South William St.
Skirrow, J. F., 253 Broadway
Slade, A. J., 289 4th Ave.
Slater, F. R., 32 Park Place.
Smith, Irving W., 420 E. 25th St.
Smith, Jesse M., 218 Broadway
Smith, T. Jarrard, 98 Fulton St.
Sprague, Frank J., 527 W. 34th St.
Steele, W. D., 26 Cortlandt St.
Stern, P. K., 130 Fulton St.
Stewart, W. M., 30 Gold St.
Stieringer, Luther, 129 Greenwich St.
Stillwell, L. B., 13 Park Row.
Stockbridge, Geo. H., 120 Broadway
Stone, J. P., 156 Fifth Ave.
Stott, H. G., 32 Park Place.
Stout, J. S., Jr., 55 Duane St.
Strauss, H. A., 32 Park Place.
Strong, J. R , 35 So. William St.
Swann, J. J., 26 Cortlandt St.
Terry. Chas. A., 120 Broadway
Tesla. Nikola, 46 E. Houston St,
Thomas, R. McK. 141 Broadway
Thompson, Edward P., 156 Fifth Ave.
Thomson, G. A., 136 Liberty St.
Thurber, H. F., 15 Dey St.
Torchio, P., 53 Duane St.
Townsend, Henry C., 141 Broadway
Townsend, Fitzhugh, Columbia Univ.
Treadwell, A., 100 Broadway
Tyng, F. E., 164 W. 27th St.
Vail, Theo. N., 26 Cortlandt St.
Vansize, William B., 253 Broadway
Van Wyck, P. V. R., Jr., 15 Dey St.
Waddell, M., 72 Trinity Pl.
Waldo, Leonard, 71 Broadway.
Warren, A. K., 120 Liberty St.
Waterman, F. N., 150 Nassau St.
Waterman, M. B., 55 Duane St.
Waters, E. G., 44 Broad St.
Weaver, W D., 120 Liberty St.
Webb, Herbert Laws, 15 Dey St.
Wells, W. F., 55 Duane St.
Weston, S. F., 330 W. 33d St.
Wetzler, Joseph. 240 W. 23rd St.
White, J. G., 29 Broadway
Whitmore, W. G., 44 Broad St.
Whitney, C. E., 61 W. 114th St.
Wightman, M. J., 50 Broadway.
Wiener, A. E., 240 W. 23rd St.
Wiley, Geo. L., 56 Liberty St.
Wiley, Wm. H., 43 E. 19th St.
Williams, A. 57 Duane St.
Willyoung, E. G., 11 Frankfort St.
Wilson, C. H., 26 Cortlandt St.
Wilson, Fremont. 66 Maiden Lane
Wintringham, J. P., 36 Pine St.
Woolf, Albert 415 Lexington Ave.
Yarnall, V. H., 302 Broadway.
Young, C. G., 29 Broadway.

New York City.—Continued.
Young, Chas. I., 120 Broadway.
Zalinski, Capt. E. L., 7 W. 43d St. 303

Official Stenographer.

Ryan, R. W., Rm. 178 P. O. B'ld'g

Niagara Falls.

Acheson, E. G., Carborundum Co.
Barton, P. P., N. F. Power Co.
Buck, H. W., 170 Buffalo Ave.
Deeds, E. A., The Natural Food Co.
Edmands, I. R., Union Carbide Co.
Imlay, L. E., 203 6th St.
Johnson, W. C., N.F.Hyd. & Mfg Co.
Lincoln, P. M., Cataract Const. Co.
Lovejoy, D. R., Cataract Chemical Co..
Price, E. F., Union Carbide Co. 10

Ogdensburg.—Jones, M. E.
Pelham Manor.—Gilliland, E. T.
Potsdam.—Dates, H. B.
Rhinecliff.—Philbrick, B, W.

Rochester.

Barnes, C. R.
Redman, G. A. 2

Schenectady.

Andrews, W. S . General Electric Co
Armstrong, A. H., " " "
Badeau, I. F., " " "
Barr, J. B., " " "
Berg, E. J., " " "
Berg, Eskil, " " "
Blackwell, F. O., " " "
Boyles, T. D., " " "
Carter, F. W., " " "
Corey, F. B., " " "
Davis, A. G., " " "
Davis, W. J. Jr., " " "
Dempster, Thos., " " "
Emmet, W. L. R , " " "
Ely, W. G. Jr., " " "
Ekstrom, Axel, " " "
Eyre, M. K., 7 Union St.
Haskins, Caryl D., Gen'l Electric Co.
Hewlett, Edw. M., " " "
Kellogg, J. W. " " "
Knox, S. L. G., " " "
Kruesi, A. H., " " "
Lohmann, R. W., " " "
Lovejoy, J. R., " " "
McClenathen, Robt., " " "
Moody, V. D., 609 State St.
Moore, J. P., General Electric Co.
Oudin, M. A., " " "
Oolgardt, J. J., " " "
Potter, W. B., " " "
Read, R. H., " " "
Reist, H. G., " " "
Rice, E. Wilbur, Jr., " " "
Rohrer, Albert, L , " " "
Sargent, H. R., " " "
Slichter, W. I, " " "
Stebbins, Theodore " " "
Steinmetz, C. P., " " "
Wirt, H. C., " " "
Woodbridge, J. E., " " "
Wood, A. B., 321 Summit Ave. 40

Syracuse.
Archbold, Wm. K., University B'ld'g.
Brady, Paul T.
Cahoon, J. B., 729 Crouse Ave.
Harter, Bret, 83 Wieting Block.
Land, Frank, 220 Green St.
Noxon, C. P. L., 500 E. Water St. 6

Tarrytown.—Crehore, A. C.

Tompkinsville.—Gregg, T. H.

Troy.—Bernard, Edgar G., 450 Fulton St.

Utica.—Nicholson, W. W., Telephone B'ld,g.

Whitestone.—Uhlenhaut, F. Jr.

Yonkers.
Cosgrove, J. F., 38 St. Andrews Place.
Ihlder, John D., Otis Electric Co.
Scidmore, F. L., N.Y.C. & H.R.R. 3

NORTH CAROLINA.

Charlotte.—
Sampson, F. D.
Smith, S. J., 202 So. Tryon St.. 2

Winston-Salem.—Barr, F. A.

OHIO.

Akron.
Pomeroy, W. D., 110 Park Place.
Shaw, E. C. 2

Cincinnati.
Baldwin, B. L., 73 Perin B'ld'g
Bogen, L. E., Univ. of Cincinnati.
Creaghead, Thos. J., 802 Plum St,
French, Thos. Jr., 713 Ridgeway Ave.
Hafer, Geo. Jr., Cinc. Gas Co.
Lilley, L. G., Cor. 3d & Walnut
Middleton, A. C., 420 W. 4th St.
Reno, C. S., 620 Baymiller St.
Rodgers, H. S., 420 W. 4th St.
White, W. F., 220 W. 8th St. 10

Cleveland.
Ambler, Wm., 76 Lincoln Ave.
Brush, Chas. F., 453 The Arcade.
Canfield, Milton C., 48 Greymont St.
Cook, E. J., 96 Commonwealth Ave.
Cowles, Alfred H., 361 Arcade.
Hoag, G. M., 113 City Hall.
Lindsay, Robert. 771 Cuyahoga B'ld'g
Roberts, E. P., Electric Building.
Sperry, E. A., 855 Case Ave.
Wason, Chas. W., 2069 Euclid Ave. 10

Columbus.
Caldwell, F. C., State University.
Edmands, S. S.
Fish, F. A., " "
Thomas, B. F., State University 4

Dayton.
Emerick, L. W., 369 W. Monument St.
Thresher, A. A. 2

East Liverpool.—Healy, L. W.

Piqua.
Lorimer, G. W.
Lorimer, J. H. 2

Norwood.—Behrend, B. A.

Salem.—Davis, Delamore L.

Toledo.—Bechtel, E. J.

OREGON.

Oregon City.—Cheney, W. C.

Portland.
Mitchell, Sidney Z., Fleischner B'ld'g
Shock, T. A. W. 2

Salem.—Anson, F. R.

PENNSYLVANIA.

Allegheny.
Smith, F. S.
Wurts, A. J. Westinghouse E.&.M.Co. 2

Altoona.
Dudley, C. B.
Elmer, Wm. Jr.
Gough, H. E., 1415 11th St. 3

Braddock.—Maccoun, A. E.

Chester.—Tidd, G. N.

Duquesne.—Friedlander E.

Ford City—Stutz, C. C.

Harrisburg.—Best, A. T., 703 Showers Ave.

Hokendauqua.—Thomas, J. W.

Munhall.—Dinkey, A. C.

Palmerton.—Bull, R. W.

Phœnixville.—Perot, L. Knowles.

Philadelphia.
Biddle, J. G., Stephen Girard B'ld'g.
Billberg, C. O. C., 3300 Arch St.
Blanchard, C. M., Union League.
Blizard, C., 19th St., & Allegheny Ave.
Bolan, T. V., 214 S. 11th.
Braddell, Alfred E., 316 Walnut St.
Bragg, Chas. A., Land Title B'ld'g
Clement, E. E., 1205 Girard B'ld'g.
Coles, E. P., 214 S. 11th St.
Cumner, A. B., 251 S. 12th St.
Darlington, F. W., 1120 Real Estate Trust Co. B'ld'g.
Drysdale, W. A., Hale B'ld'g
Eglin, J. M., 10th and Sansom Sts.
Eglin, W. C. L., Cor. 10th & Sansom.
Entz, J. B., 19th St. & Allegheny Ave.
Firth, W. E., Nicetown
Foster, H. A., 650 Bullitt Bldg.
Gallaher, E. B., Drexel Bldg.
Gharky, W.D., 2347 Park Ave.

Philadelphia.—Continued.

Hall, J. L., 608 N. American B'ld'g.
Hartman, H. T., 1406 Land Title Bg.
Hering, Carl, 929 Chestnut St.
Hewitt, Chas , 809 Spruce St.
Hodge, W. B., 1010 Chestnut St.
Houston, E. J., 1203 Crozer B'ld'g
Hunter, Rudolph M , 926 Walnut St.
Kennelly, A. E., 1203 Crozer B'ld'g
Lafore, J. A., 125 So. 11th St
Leeds, M. E , 259 No. Broad St.
Levis, Minford, 54 North 4th St.
Lloyd, Herbert, 19th & Allegheny Ave.
Marks, W. D., The Art Club.
Patton, P. I., 1026 Filbert St.
Pike, C. W., 112 N. 12th St.
Reed, C. J., 3313 N. 16th St.
Rowland, A. J., Drexel Inst.
Satherberg, C. H., Nicetown
Scott, W. M., 108 W. Johnson
Smith, Irving B., 1028 Filbert St.
Smith, T. Carpenter, 650 Drexel B'ld'g
Smith, W. E., 19th & Allegheny Ave.
Smith, W. F., Un. Gas. Imp. Co.
Spencer, Paul, Broad & Arch
Spencer, Theo., 11th and Filbert Sts.
Stakes, D. F., 1500 Land Tftle B'ld'g
Stanton, C. H., 1517 Walnut St.
Stevens, J. F. 9th St. & Montgomery Av.
Stitzer. A. B.. Union Traction Co.
Swoope, C. W., Spring Garden Inst.
Toerring, C. J., 1035 Ridge Ave.
Walmsley. W. N., 1002 Harrison Bldg.
Winand, P. A. N., 3200 Arch St.
Wise, J. S., Jr., 2023 Mt. Vernon St. 52

Pittsburg.

Auel. C. B., Westingh. E. & M. Co.
Austin, S. B , 3912 Fifth Ave.
Beebe, M. C., Amber Club.
Blakemore, M. N., Westing. E.&M.Co.
Converse, V. G., 15th St. & Liberty Av.
Davis, H. P., Westinghouse E & M.Co.
Dunlap, W. K., West'house E.& M. Co.
Fisher, H. W. Standard Und. Cable
Hill, E. R., Westinghouse E. & M. Co.
Hommel, L., 618 Westinghouse B'ld'g.
Hutchinson, F. L., " " "
Keller, E E., West'house E. & M. Co.
Lange, Philip A., " " "
Merrill, J. L., Park B'ld'g.
Nock, Geo. W. " " "
Osborne, L A., West'house E.&M. Co
O'Sullivan, M. J., Sylvan Ave.
Peck, J. S., Westinghouse E. M. & Co.
Rockwood, D. C., " " "
Scott, Chas F. " " "
Skinner, C. E., " " "
Storer, N. W., " " "
Stuart, H. R., " " "
Thomas, Percy H., " " "
Tingley, E. M., " " "

Pittsburg.—Continued.
Temple. W. C., Bank of Commerce Bg.
VanVleet, R. M., Westing.E. & M.Co.
Viehe, J. S., Westinghouse E.& M.Co.
Wallau, H. L., " " "
Winslow, G. H., 339 Fifth Ave.
30

Reading.—
Brown. E. E.
Klinck, J. H., 5 So. 9th St. 2

Rochester.—Sage, H. J.

Scranton.

Elias, A. B., 1310 Washington St.
Webb, H. S., 225 Jefferson Ave.
2

South Bethlehem.

Franklin, W. S., Lehigh Univ.
MacFarlane, Alexander
2

State College.—Jackson, Prof J. P.
Swarthmore.—Stine, W. M.
Tamaqua.—Spiese, F. P.
Towanda.—Dunston, R. E.
Vandegrift.—Pinkerton A.

Wilkesbarre.

Harvey, R. R., 10 S. Franklin St.

RHODE ISLAND.

Lonsdale —Ellis, John

Phillipsdale.

Phillips, E. F.
Varley, R. Jr 2

Providence.

Downes, L. W., 407 Pine St.
Lisle, A. B., 60 Weybosset St.
Woodward, W. C., 60 Weybosset St. 3

Woonsocket.—Ballou, W. J.

SOUTH CAROLINA.

Pelzer.—McKissick, A. F.
Spartanburg.—Knox, F. H.

TENNESSEE.

Chattanooga —Burt, B. T.

TEXAS.

Houston.—Reed, W. W.

UTAH.

Park City.—Fleming, J. B.

VERMONT.

Bellows Falls —Bottomley H.
Burlington,—Freedman, W. H.
Rutland.—Francisco, M. J.

VIRGINIA.

Blacksburg.—Randolph, L. S.

Hot Springs.—Stewart, J. B.

Norfolk.—Wright, Peter

Newport News.

Crain, J. J.
Loomis. O. P. 2

Portsmouth.

Hardy, Carl E., U. S. Navy Yard.
Thompson, J. P., U. S. Navy Yard 2

Richmond.

Brown, H. T., Box 47.
Gillis, H A., Richmond Loco. Works.
Johnston, A. L., 1112 E. Main St,
McCluer, C. P., W. R. Trigg Co.
Tower, Geo. A., 704 E. Main St.
Trafford, E. W., 413 N. 7th St.
Willis, E. J., 211 E. Franklin St. 6

WASHINGTON.

Everett.—Butler, William C.

Seattle.

Baldwin, G. P., 507 Pioneer B'ld'g.
Doubt, T. E.
Ellis, R. L.
Huggins, N. W.
Joslyn, Howard, 507 Pioneer B'ld'g.
Maxwell, E.
Millis. Maj. John
Robinson. D. P. 8

Spokane.—Howes, Robt., Box 1587

WEST VIRGINIA.

Charleston.—Johnson, H. S.
Wheeling.—Sands, H. S.

WISCONSIN.

Madison.

Burgess, C. F., Univ. of Wisconsin
Frankenfield, B., 609 Lake St.
Jackson, Dugald C., Univ. of Wis.
Swenson, B. V., 606 Francis St. 4

Milwaukee

Berresford, A.W., 12th St. & St. Paul Av.
Finney, J. C., 1 & 3 Old Insur. B'ld'g.
Robinson, Geo. P., Wis. Tel. Co.
Schmidt, C. J.
Wilson, C. P., 451 Broadway 5

HAWAIIAN ISLANDS.

Hilo.—Sedgwick, C. E., Hilo Elec. Light Co.

Honolulu.

Cassidy, John, Mutual Telephone Co.
Cooke, G. A., Hawaiian Elec. Co,
Gartley, A., Hawaiian Elec Co.
Grant, L. T., Box 536.
Hasson, W. F. C., Judd B'ld'g.
Pratt, R. J., Honolulu Iron Works
Wolf, L. H., Box 252. 7

PHILLIPINE ISLANDS,

Cavite.—Smith, W. Stuart.
Manila.—Squier, Capt. G. O.

PORTO RICO.

San Juan.—Parks, C. Wellman.

DOMINION OF CANADA.

BRITISH COLUMBIA.

Vancouver —

Dunn, K. G.
Walkem, G. A. 2

Victoria.

Sperling, R. H., B. C. E. R'way Co.

NOVA SCOTIA.

Baddeck.—Bell, A. Graham
Halifax.—Winfield, J. H.
Hazel Hill.—Dickenson, Samuel S.

ONTARIO.

Hamilton.—Leyden, H. R.

Ottawa.

Ahearn, T.
Dion, Alfred A., 72 Sparks St.
Murphy, John, Ottawa Elec. Co.
Thomson, C., Patent Office.
Trudeau, J. A. G., 329 Kent St. 5

Rat Portage.—McCrossan, J. A.

St. Catharines.—Cheney, F. A.

Toronto.

Kammerer, J. A., 87 Jameson Ave.
Parke, R. H., 409 Temple Bldg.
Rosebrugh, Thomas R
White-Fraser, Geo., 18 Imp'l Loan Bg. 4

QUEBEC.

Montreal.

Burnett, J. A., 94 Queen St
Gossler, P. G., 94 Queen St.
Herdt, L. A., McGill University
Howland, L. A., 6 Queen St.
Jaquays, H. M. 94 "
Mudge, A. L., G. T. Railway.
Owens, R B., McGill University.
Robertson, J. McC., 94 Queen St.
Ross, Robert, A., 17 St. John St.
Sise, Charles F. P. O., Box 2262
Taylor I. A., McCord & Seminary Sts.
Thornton, K. B., 94 Queen St.
Weller, H. W., 202 St. James St.
Wilson, R. M., McGill University. 12

MEXICO.

C. Victoria, Tamps.—Rossi, H. J.

Durango.—

Carnaghan, E. D.
Guerrero, J. 2

Indianilla, D. F.—Johnson, C. E.

Jalapa, V. C.—

Yslas, Carlos
Gutieriez, M. B.
Greenwood, G., Jalapa R'y & Power Co. 3

Guadalajara.—

Schiaffino, M. L.
Thompson, J. W. 2

Mexico.

Barnes, H. H., Mex. Elec. Works.
Beames, C. F., 71^{A} San Francisco.
Bowman, J. H.
Dyer, S. A., Box 403.
de Waal, W. H.,Cardena No. 3.
Evans, C. W., Box 2100.
Evans, P. H., Mex. Gen. Elec. Co.
Henry, L. W., Mex. Gen. Elec. Co.
McCreary, J, L., Dist. R'way Co.
Niles, H. B. American Club.
Shearer, J. H., Nat. Elec. Light Co.
Shepard, R. R., Box 403.
Somellera, G. F., Box 115.
Thompson, M. T., Box 403,
Worswick, A. E., 3rd Calle des las Artes
Zapata, J. M., Gen. Elec. Co.
16

Monterey.—Dysterud, E.

Pachuca.—Renstrom, F. A.

Puebla.—Wilson, H. S.

Tamaulipus.—Rossi, H. J.

CENTRAL AMERICA.

GUATEMALA.

Quezaltenango.—Morehouse, H. H.

SOUTH AMERICA.

ARGENTINE REPUBLIC.

Buenos Aires.

Abella, Juan, 766 Calle Bolivar
Brayshaw, I., Great Southern Railway
McCrosky, J. W., Reconquista 20
Parker, L. H. Calle Santa Fe 2457
4

UNITED STATES of BRAZIL.

Para.—da Cunha, Manoel Ignacio, Empresa Industrial Gram-Para

Rio Janeiro.—Mitchell, James

CHILI.

Santiago.

Currie, N. M.,
Jones, G. H., Casilla 1317
2

PERU.

Lima.—Davidson, A.

WEST INDIES.

CUBA.

Havana.—Thompson, A. J., O'Reilly 15

JAMAICA.

Kingston.

Campbell, H. A., 38 Harbor St.
Davis, L. F., " "
Roberts, Allen D., 12½ King St.
Wilson, Harry C. 4

AFRICA.

CAPE OF GOOD HOPE.

Cape Town.

Denham, John
Lloyd, J. E. 2

NATAL.

Durban.—Kirkland, J. W.

SOUTH AFRICAN REPUBLIC.

Germiston—Peirce, A. W. K., Box 217

Johannesberg.—Gorrisen, Ch., Box 2671.

ASIA.

INDIA.

Bunno.—Beveridge, E. W.

Negapatam.—Vanderveen, A. R.

JAPAN.

Kiota.—Namba, M.

Beppu.—H. Maki

Hiogo Ken.—Misaki, S.

Tokyo.

Baugher, E. C.
Tachibara, Jin
Iijima, Z.
Iwadare, K.
Oi, S. 5

Yokohama.

Bayley, G. L.
Brenner, W. H.
Dyer, E. I. 2

AUSTRALIA.

NEW SOUTH WALES.

Sydney.

Allan, John, 54 Margaret St.

Sydney.—Continued.

Fischer, Gustave J., Public Works Dep't
Fitzmaurice, Jas. S., 210 George St.
Goodman, W. G. T., Pub. Works Dept.
Hanson, A. J., 3 Wynyard St.

5

VICTORIA.

Melbourne.—
Jones, A W.
Tolman, C. M., Deep Leads Trans.Co.

2

WESTERN AUSTRALIA.

Perth—Wall, L. J. B.

NEW ZEALAND.

Auckland.—Rich, F. A.
Otaki.—Lemon, Charles
Wellington.—Dawson, Josiah

EUROPE.

AUSTRIA – HUNGARY.

Buda-Pesth.—Jehl, Francis
Vienna.
Egger, E., X. Simmerlngstr, 187
Sahulka, Dr. Johann, Technische Hochschule

2

GREAT BRITAIN.

ENGLAND.

Beer.—Trott, A. H. H.
Blundellsands.—Inrig, A. G.
Bolton-le-Moors.—Jackson, Henry
Bristol.—Williams, G. H.
Croydon.—Lewis, H. F. W.
Hampstead.—Donner, W. H.
Hyde.—Adamson, D.
London.
Blunt, W. W., Norfolk St.
Burton, W. C., 22A College Hill.
Churchill A. 83 Cannon St
Carus-Wilson C. A., 41 Old Queen St.
Daft, Leo, 50 Hartfield Road.
Dawson, P., 39 Victoria St.
Forbes, Geo., 34 Great George St.
Fortenbaugh, S. B., 112 Cannon St.
Hermessen, J. L., 83 Cannon St.
Hewlett, E. H., 28 Victoria St.
Kelvin, *Lord*, 15 Eaton Place.
Little, C. W. G., Donington House.
Lorrain, James Grieve, Norfolk House

London.—Continued.
Macartney, J. F, 53 Victoria St.
McCarter. R. D., 110 Cannon St.
Merz, C. H., 28 Victoria St.
Mordey, Wm. M., 82 Victoria St.
Osborne, M., 83 Cannon St.
Parry, Evan, 8 Princes St. Bank
Parshall, A., 83 Cannon St.
Parshall, H. F. 8 Princes St. Bank
Perry, John, Royal Coll. of Sci.
Preece, *Sir.* Wm., 13 Queen Anne's Gate.
Reid, E. S., 23 College Hill.
Rutherford, W., 110 Cannon St.
Salomons, *Sir* D. L., 49 Grosvenor
Swinton, A. A. C, 66 Victoria St.
Thompson, S. P., West Hampstead.
Thompson, W. R., 22A College Hill.
Walker, Sydney F. 2 Kens. Gard Sq.
Webber, Maj. Gen. C. E., 17 Egerton Gardens.
Wharton, Chas. J., Palace Chambers
Winslow, I. E., 35 Parliament St.

32

Manchester.—Wordingham, C. H.
Riding-Mill-on-Tyne.—Dobbie, R. S.
Surrey.—Sparks, Chas. P.
Taunton.—Haynes, F. T. J,

FRANCE

Grenoble.—Stahl, Th.
Nice.—Albanese, G. Sacco.
Paris.
Coster, M., 45 Rue de la Arcade.
Garfield, A. S., 5 Villa Michon
Le Blanc, Chas., 7 rue Meyerbeer.
Leutheule, Paul, 27 Rue de Londres
Mix. Edgar W., 12 Boul.des Invalides.
Schmid, A., 45 Rue de l'Arcade.
Stephens, George, 219 Rue de Vangirard
Thurnauer, Ernst, 27 Rue des Londres
Tripier, H., 17 Rue Caralloti
Welles, F. R., 46 Ave. De Breteuil

10

GERMANY.

Berlin.
Burke, Jas., Klopstockstr. 15
de Nordwalls, Chas. F., 22 Schiffbauerdamm.
Hakonson, H. Westend.
Heinrich, R. O., Ritterstrasse 88
Hobart, H. M., Union Elec. Ges.
Hulse, W. S., Dorotheen Str. 43.
Magee, Louis J., Grosse Quer Allee 1

Berlin.—Continued.

Rathenau, E., 22 Schiffbauerdamm
Schum, C. H., Oudenarder Strasse, 30
Tischendoerfer, F. W., Union Elektricitats Gesellschaft
West, Julius H., Handjery Str. 58 Friedenau, near Berlin.
Wieselgreen, C. E., Allgemeine Electricitats Gesellschaft.
12

Darmstadt, Kittler, Dr. E., Schwanthalerstrasse

Hannover.—Meyer, H. S Alleestrasse 7D.

Munchen.—Voit, Dr. Ernst

ITALY.

Ivrea —Olivetti, Camillo.

Milan.—

Pfeiffer, A. J. J.
Zani, A. P.
2

Turin.—Capuccio, M.

NETHERLANDS.

Amsterdam.

Hubrecht, Dr. H. F. R.
Otten, Dr. J. D., Van Baerlestraat 10
2

Delft.—Doyer, H.

PORTUGAL.

Lisbon.—Cole, W. H.

RUSSIA.

Kiev.—Browd, P. K.,
Odessa.—Moschkowitsch, M. S.
Riga.—Hassler, C. T. F.
St. Petersburg.—de Chatelain, M. A

SWEDEN.

Westeras.—Danielson, Ernest

SWITZERLAND.

Baden.—de Muralt, C. L.

Geneva.—Field, S. D.

Addresses Unknown.

Degen, L.
De Redon, C.
O'Dea, M. T.
3

Notice.

The Secretary would be pleased to receive the present addresses of the above.

(26) Total, 1269.

INDEX.

BUSINESS OF THE INSTITUTE.

SUBJECTS DISCUSSED BEFORE THE INSTITUTE.

AUTHORS OF PAPERS AND PARTICIPANTS IN DISCUSSIONS.