

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, April 26, 1901.

The 153rd 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 Executive Committee this afternoon, the following Associate Members were elected:

Name	Address	Endorsed by
ANDERSON, DOUGLAS SMITH	Professor of Electricity and Electrical Engineering, University of Mississippi, University, Miss.	Brown Ayres. Harris J. Ryan. Edw. L. Nichols.
BREWSTER, WALTER SCOTT	Electrician, Standard Underground Cable Co., 205 Market St., Perth Amboy, N. J.	H. W. Fisher. A. J. Rowland. R. A. Fessenden.
BURNETT, JAMES AUBREY	Draftsman and Designer, Royal Electric Co., 94 Queen St., residence, 19 Shuter Street, Montreal, P. Q.	P. G. Gossler. R. B. Owens. Ernst J. Berg.
CLARK, FARLEY GRANGER	Electrician in charge 96th St. Power Station, Metropolitan St. Ry. Co., 96th St. and 1st Ave., residence, 439 Manhattan Ave., New York City.	W. N. Ryerson. P. Torchio. J. J. Mahoney.
CLOUGH, DWIGHT EDWARD	Electrician, Buffalo and Lockport Railway, Lockport, N. Y.	P. Eskil Berg. H. S. Webb. C. E. Gifford.
GILLIS, HARRY ALEXANDER	General Superintendent, Richmond Locomotive Works, Richmond, Va.	Gano S. Dunn. Wm. S. Aldrich. Thos. V. Bolan.
HAUBRICH, ALEX. MICHAEL	Electrical Engineer, Central Union Telephone Co., 1309 Ashland Block, Chicago, Ill.	H. S. Carhart. S. G. Mc Meen. B. J. Arnold.
HODGES, WILLIAM LEMMON	Asst. Engineer, The Keystone Telephone Co., 750 Drexel Bldg., residence; 3453 Woodlawn Ave., Philadelphia.	Louis Duncan. J. J. Carty. Henry Floy.

HOPTON, WALTER EDWIN	General Superintendent Cincinnati Edison Electric Co., Cincinnati, O.	A. N. Mansfield. F. E. Idell. W. K. Archbold.
KILGOUR, MARTIN HAMILTON	Borough Electrical Engineer, Corporation Electric Works, 2 Church Street, Cheltenham, England.	W. H. Preece. C. H. Wordingham W. M. Mordey.
LEEDS, MORRIS EVANS	Managing Member of the firm, Morris E. Leeds & Co., 259 North Broad St., residence, 3221 N. 17th St., Philadelphia, Pa.	Edwin J. Houston Chas. J. Reed. Carl Hering.
Mc BERTY, FRANK R.	Telephone Engineer, Western Electric Co., Chicago, Ill., residence, Evanston, Ill	T. D. Lockwood. I. H. Farnham. F. A. Pickernell.
MONRATH, GUSTAVE	Engineer and Superintendent, Grace & Hyde Engineering Co., residence, 26 E. 42d St., New York City.	C. G. Armstrong. H. B. Coho. M. Coster.
ROBERTSON, JAS. McCALLUM	Superintendent, Power Department, The Royal Electric Co., Montreal, P. Q.	Norman Ross. P. G. Gossler. Ralph D. Mershon
THORNTON, KENNETH BUCHANAN	Superintendent Line Department, The Royal Electric Co., residence 840 Dorchester Street, Montreal, P. Q.	P. G. Gossler. H. R. Leyden. R. M. Wilson.

Total 15.

The following Associate Members were transferred to full Membership.

Approved by Board of Examiners, March 18th, 1901.

BUCK, HAROLD WINTHROP	Electrical Engineer, Niagara Falls Power Co., 170 Buffalo Avenue, Niagara Falls.
BURGESS, CHARLES FREDERICK	Assistant Professor, Electrical Engineering, University of Wisconsin, 609 Lake Street, Madison, Wis.
FISHER, HENRY WRIGHT	Electrician and Director of Electricity and Chemical Laboratories, The Standard Underground Cable Co., Pittsburg, Pa.
HAFFER, GEORGE, JR.	General Superintendent and Electrical Engineer, Cincinnati Gas Co., Electric Department, Cincinnati, O.
KENAN, WILLIAM RAND, JR.	Traders' Paper Co., Lockport, N. Y.
MURPHY, JOHN	Superintendent, Power Houses, The Ottawa Electric Co., Ottawa, Ont.
SPRINGER, FRANK WESLEY	Assistant Professor Electrical Engineering, University of Minnesota, Minneapolis, Minn.

The President announced that the Council had prepared and now submitted in writing an amendment to the Constitution, which would be brought up for consideration at the Annual Meeting May 21st.

DR. SAMUEL SHELDON :—Mr. President, before those amendments are read, I would like to make a motion—inasmuch as we have two papers for this evening—that Mr. Dunn make a digest of the amendments and present to us the radical changes, omitting those parts which are common to both Constitutions. [Carried.]

Mr. Dunn having outlined the proposed changes in the Constitution, it was voted that the new Constitution, as revised by the Committee, be printed and distributed to the membership before the next meeting.

Prof. Harris J. Ryan then presented the following paper on “The Transformer for Measuring Large Direct Currents.”

THE TRANSFORMER FOR MEASURING LARGE DIRECT CURRENTS.

BY HARRIS J. RYAN.

In operating practice, the use of the transformer for the measurement of large alternating currents is now widely adopted. No similar operating use of the transformer can be made for direct currents. This paper, however, presents *a method for large direct current calibrations* that employs the transformer for comparing the values of large and small currents in terms of the ratio of transformation and the reading of the instrument used for measuring the small current. The method is based upon the following principle:

Where two direct current carrying coils of similar dimensions are placed side by side and linked with a closed laminated iron core of low reluctance, the permeability of this core for alternating magnetic flux will be a maximum when the ampere turns of the two coils are equal and opposite.

The test for maximum permeability to alternating flux may be applied in various ways. I have found the one given by the diagram of Fig. 1 to work very well. In this diagram A-1 is an ammeter that has been recently standardized by reference to the Clark cell and a Reichsanstalt resistance. A convenient range for this instrument is from 0 to 25 amperes. With reference to A-1, the heavy direct current shunt and milli-voltmeter type of ammeter is to be calibrated, checked or adjusted. The ampere turns produced by the small current drawn through the secondary coil, B, mounted on the core, C C, and the ammeter, A-1, are to be balanced against the ampere turns produced by the large current through the single primary turn, A, and the

ammeter, A-2. In circuit with A-1 and B there is a water rheostat conveniently arranged so that the current on this circuit may be smoothly yet quickly adjusted to any desired value. The auxiliary primary and secondary circuits, *a* and *b*, the two two-part commutators mounted and driven on the same shaft, and the galvanometer, G, are for the purpose of noting when the permeability to alternating flux of the core, C C, is a maximum, as the current in A-1 and B is changed to bring the ampere turns of B equal and opposite to those in A due to the large continuous current.

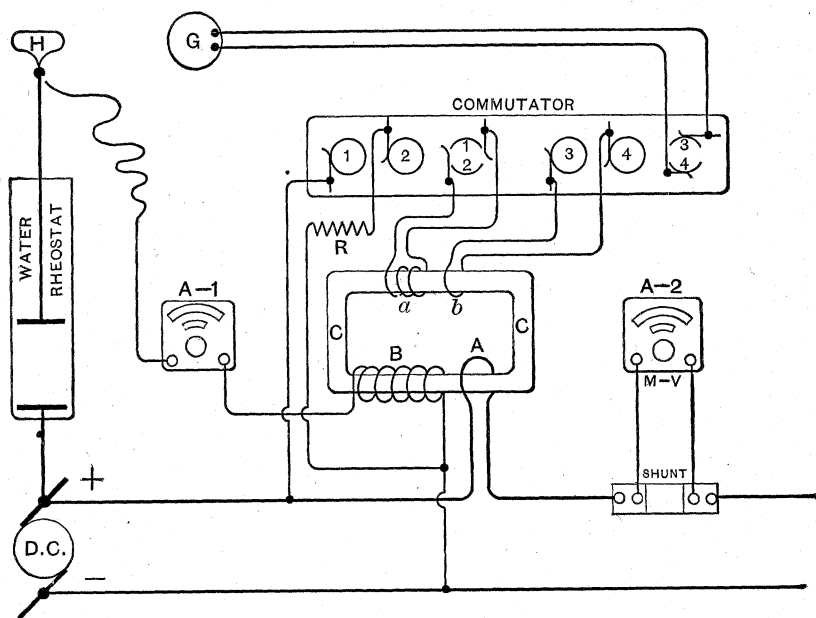


FIG. 1.

The alternating current through the primary, *a*, which provides the necessary small alternating m.m.f., is obtained by passing a direct current of one or two amperes from the large direct current source, D.C., through the controlling resistance, R, the revolving two-part commutator, 1-2, and as alternating current through the small auxiliary primary, *a*. The secondary, *b*, contains one turn which connects with alternating current through the revolving two-part commutator, 3-4, and with rectified current through the galvanometer, G. The two-part commutators are mounted and driven on the same shaft. The brushes of

these commutators are set on diameters that are at right angles to one another. Thus b is definitely connected to the galvanometer, g , at each reversal of the current that occurs through a . In our trials of this method we drove the commutator shaft from a fan motor. The commutators can easily be made light enough to be driven by clockwork if so desired.

At a given commutator speed and current running through a , the galvanometer, g , will give a maximum deflection when there are no currents in A and B , or when the ampere turns of those coils are equal and opposite. To determine the current in $A-2$ in terms of $A-1$, an observer at the galvanometer adjusts the current through $A-1$ and B by means of the water rheostat until a maximum deflection is obtained at g , at which point the instru-

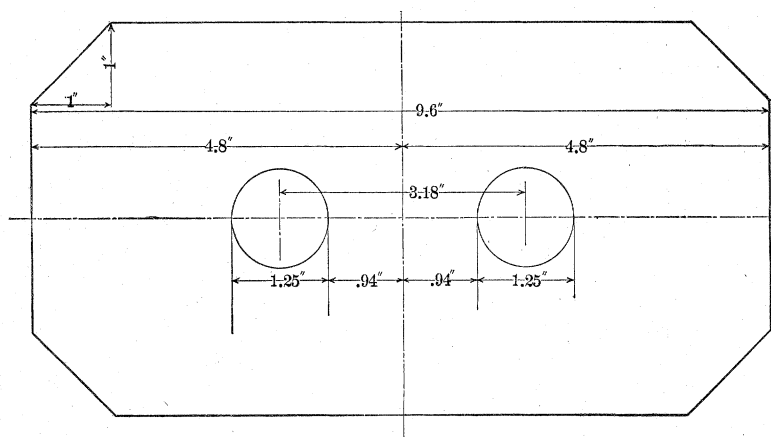


FIG. 2.

ments, $A-1$, and $A-2$ must be simultaneously read. The value of the current through $A-2$ is the current through $A-1$ multiplied by number of turns in B ,— A having one turn.

TRIAL OF THE METHOD.

A transformer for this purpose was constructed having the following specifications and dimensions:

The Core.—The core was built of .016" Apollo transformer japanned steel sheets. The shape and size of each sheet are given in Fig. 2. Total number of sheets, 117.

The Current Coils.—For convenience in checking the results, a ratio of transformation of unity was adopted, *i. e.*, the coils A and B as indicated in the diagram of Fig. 1, consisted each of 15 turns of No. 10, B & S. G.

The Alternating Induction Coils.—The coil, *a*, contained 27 turns of No. 18 B. & S. G., and the coil, *b*, contained one turn.

The transformer was connected with testing circuits and facilities in all respects as described in connection with Fig. 1. The galvanometer used at *G* is a "Queen Portable" that gave a deflection of one small division per .0008 volt. It has a range of 15 small divisions, plus or minus.

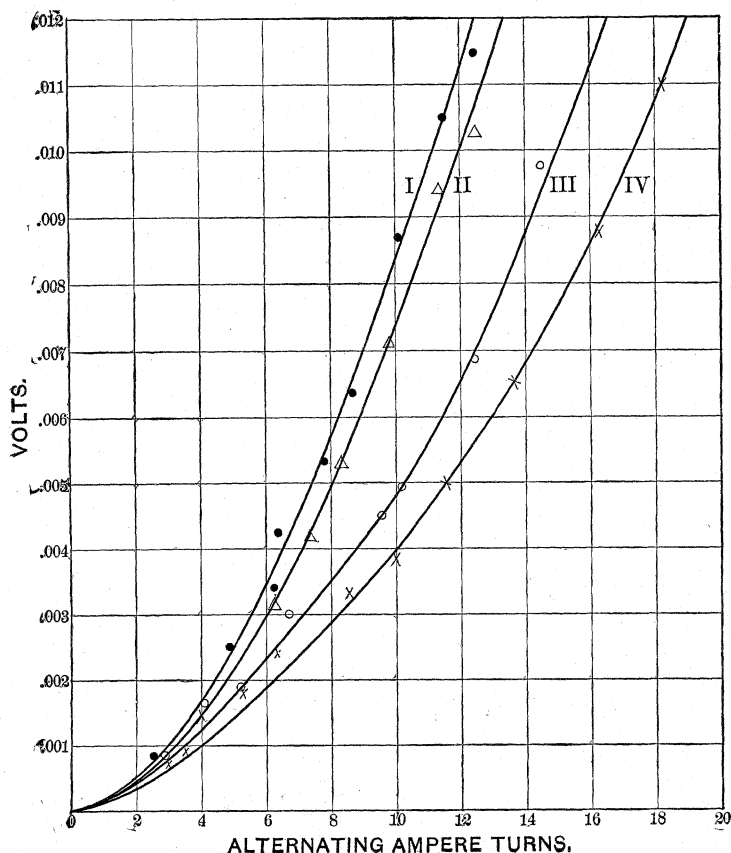


FIG. 3.

FIRST EXPERIMENT.

A series of observations was first made to determine the sensitiveness of the core to changes in permeability for alternating induction when subjected to direct current M.M.F.'s. in either of the coils, A or B., under the action of various magnitudes of alternating M.M.F.'s. The results of these observations are given by

the curves in Fig. 3. For example, curve I was obtained by applying different values of alternating current through the coil, *a*, see Fig. 1, and at each value observing the reading of the galvanometer, *G*, when no current was passing through either current coil, *A* or *B*. Curve II was obtained in the same manner except that a small direct current was passing through *one* of the current coils, *i. e.*, either *A* or *B*. The amount of this current was

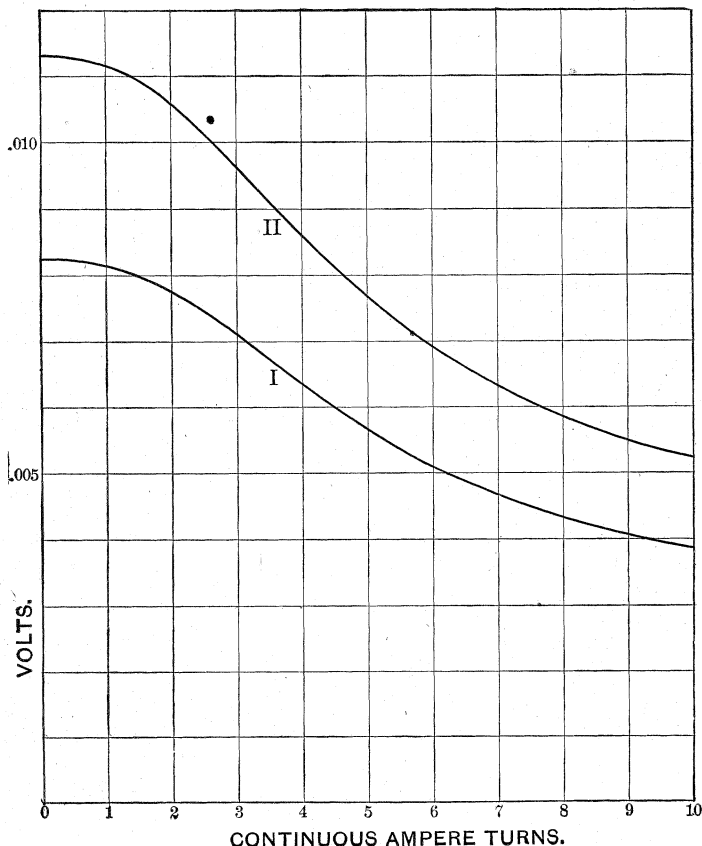


FIG. 4.

such as to produce in 15 turns a M.M.F. of 2.8 ampere turns. The remaining curves, III and IV were determined in the same manner for M.M.F.'s. in one of the current coils of 6.62 and 9.91 ampere turns.

An inspection of the curves enables one to determine the number of alternating ampere turns that should be applied as a minimum for observing when the continuous current in the coils

A and B are equal; likewise approximately the accuracy obtainable with this method. Thus at 10 alternating ampere turns the volts obtained at G are read from each of the curves I, II, III and IV of Fig. 3. These values when plotted with their corresponding continuous current ampere turns maintained in one of the current coils, form the curve, I, drawn in Fig. 4. In the same figure, curve II is correspondingly drawn for 12 ampere turns.

An inspection of these curves in Fig. 4 shows that the galvanometer deflection remains near the maximum regardless of the amount of continuous M.M.F. applied from 0 to 1 ampere turn. In addition to this the galvanometer required a change of .0004 volts to enable the observer to be readily certain that such change was due to passing beyond the ampere turn balance in the current coils and not due to slight speed variations. From curve II in Fig. 4 it is seen then that a difference of two ampere turns must exist between the M.M.F.'s of the current coils before an ample falling off in the galvanometer, G, deflection has occurred to be easily caught by the observer. Where the transformer of the above dimensions is worked to 100 ampere turns in each of the coils, A and B, an error of $\pm 2\%$ would thus be made; at 500 ampere turns the error would be $\pm .4\%$; and at 1000 ampere turns $\pm .2\%$. The transformer here tried could not be worked beyond 200 ampere turns without undue heating.

With care in manipulation these errors may be largely eliminated. We found that the best results in this respect are obtained when the observer at G changes the balancing current uniformly in one direction until he notes that the balance has been passed; he then changes the current in the opposite direction until the balance is again passed as shown in the first slight diminution in the reflection at G. The observer then holds the water rheostat in the midway position and announces the balance, when the observers at A-1 and A-2 read. The curves I and II in Fig. 4 also show that there is no advantage in using more than 12 alternating ampere turns in this particular transformer through the coil, A.

SECOND EXPERIMENT.

In this experiment a trial was made to determine identical currents in the coils A and B. Two Weston 15-ampere ammeters were used for A-1 and A-2. They were carefully compared with one another by passing current through them in series.

A continuous current was set up through A, and current was turned on through B, and adjusted until G indicated a maximum at which moment A-1 and A-2 were read. The following tables give the observations made in this manner by various observers as stated, who manipulated the water rheostat, and announced the balance observed at G. Each observer was instructed to pass the balance in both directions by increasing and decreasing the balancing current, and then to set the water rheostat in the middle position, when announcing the balance. The current source, D.C., Fig. 1, was from a 125-volt, 50 k.w. Edison dynamo that was driven by hand controlled water power and engaged upon an additional fluctuating laboratory load. All current values were for this reason more or less constantly on the move:

Mr. Hoxie, observer at G:

	A-1.	A-2.
No. 1	9.95	9.93
2	9.80	9.77
3	9.75	9.75
4	9.70	9.74
5	9.75	9.84
Average	9.79	9.81

Mr. Norris, observer at G:

	A-1.	A-2.
No. 1	9.60	9.62
2	10.48	10.48
3	10.55	10.57
4	10.54	10.49
5	10.56	10.34
Average	10.35	10.30

Mr. Cowing, observer at G:

	A-1.	A-2.
No. 1	10.40	10.34
2	10.41	10.40
3	10.40	10.40
4	10.44	10.45
5	10.41	10.43
Average	10.41	10.40

It is seen that the errors thus made range from plus two-tenths of one per cent. to minus five-tenths of one per cent.

two coils. Thus the coils were thoroughly interlaced and could not produce appreciable magnetic leakage.

It was necessary then to determine the error due to magnetic leakage which in the ordinary transformer gives rise to transformer self-induction. For this purpose I used a transformer that had been designed to work as an alternating current multiplier. It was intended to multiply the current range of a 25-ampere instrument 40 times, so that it could be used in a 1,000-ampere circuit. Transformers for such purpose do not have to approach perfection in the elimination of self-induction. The construction of this transformer is given in Figs. 5, 6, 7, 8 and 9. The construction details given in these figures are so complete that no further description is necessary.

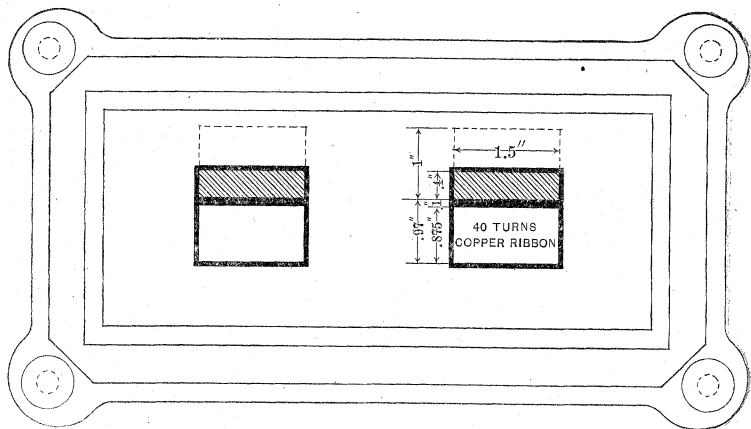


FIG. 6.

It should be noted that the peculiar construction of the 1,000-ampere single-turn coil where it passes through the core is for the purpose of lessening as much as possible, the primary and secondary conductor cross-sectional area that must be enveloped by the core. Thus the core reluctance is diminished to a minimum—a very desirable feature for an alternating current multiplier. This is accomplished by the loss of some additional E. M. F. through magnetic leakage or transformer self-induction—a point not important, as stated above, in current multipliers.

This transformer is well-suited for trial to determine the effect of internal magnetic leakage upon the accuracy of the direct-current transformer-balance. Currents up to 1,000 amperes were

furnished from a 2-volt direct-current generator through the single-turn coil, and balancing current was supplied through the 40-turn coil from a 110-volt direct-current machine. The heavy current was measured by means of a British Board of Trade .0001-ohm, 1,000-ampere resistance standard and a Weston millivoltmeter that had been calibrated by reference to a Carhart-Clark cell.

The balancing current was measured in the same manner, using a .01-ohm Reichsanstalt low resistance standard and a millivoltmeter, also calibrated by reference to the standard cell. The

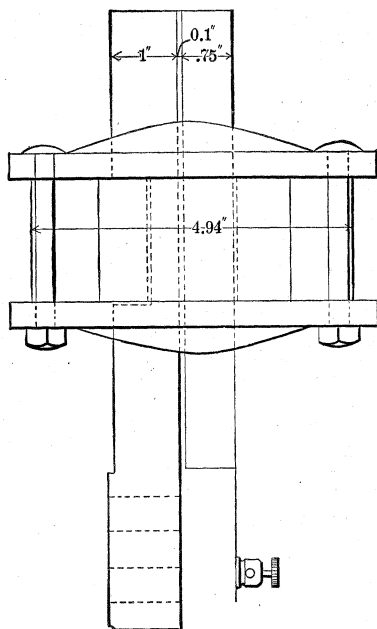


FIG. 7.

British and German resistance standards were compared with one another and found to be in agreement. The following results were obtained:

Amperes.	Ampere Turns.	Ratio.
40.6	40.2	1.010
157	154	1.020
500	476	1.051
648	621	1.044
1035	996	1.038

errors, and which is conveniently applied under most practical conditions is illustrated in Fig. 10. Upon the laminated core are wound the ampere-turn balancing coil, and the few primary and

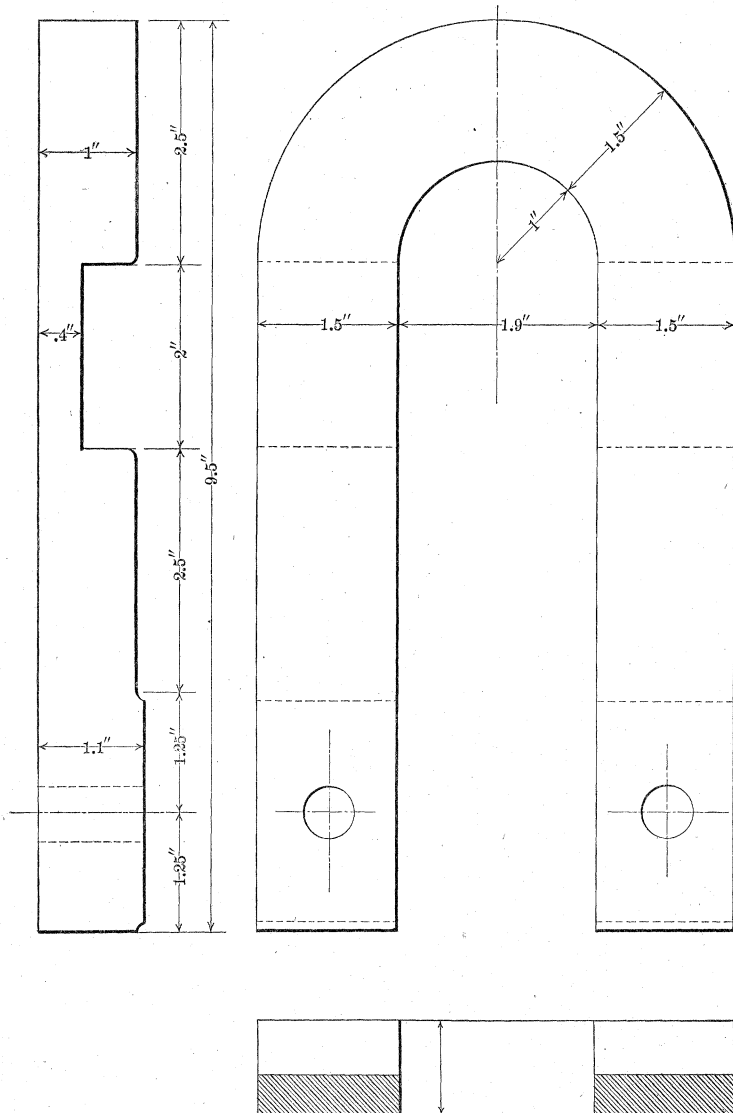


FIG. 9.

secondary turns for the alternating balance test. The core when wound is so shaped as to form a link that makes an easy fit over

the heavy conductor which carries the large current to be determined.

In Fig. 10 there is a single view of a transformer of this kind that Prof. J. O. Phelon constructed and assisted me to test.

The core is one-half inch square and one-quarter square inch in cross-section. The material in the laminations is continuous; no magnetic joints can be allowed in these cores. The laminations were cut from 14 mil Apollo electrical steel sheets.

The alternating primary contains 20 turns, and the secondary 10 turns.

The heavy direct current conductor measures $2\frac{5}{8}$ " by $\frac{9}{16}$ ". The ampere turn coil is wound with 68 turns of No. 10 B. and S. cable.

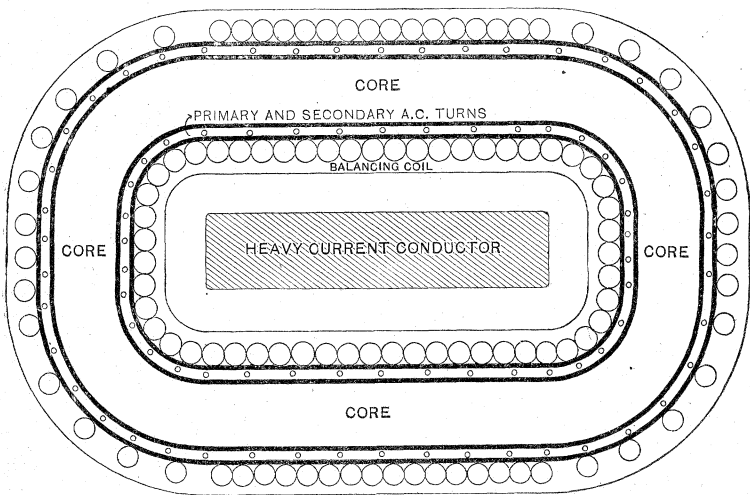


FIG. 10.

The mean length of the core is approximately 12 inches. The primary alternating current was supplied by 1.25 amperes of direct current passed through the two-part commutator. The alternating ampere turns applied to the core were, therefore, 25, or about two alternating ampere turns per inch of core. I usually drive the commutator from a small motor at a speed of 500 R.P.M.

In testing this transformer for error, the same instruments, standard and current sources were employed as when testing for the error due to magnetic leakage.

The following results were obtained :

Amperes.	Ampere Turns.	Ratio.
238.7	238.7	1.0000
712.6	713.2	.9991

Each of the above set of values is the average of five sets of readings taken at five corresponding balances.

These excellent results were obtained by taking current from a fluctuating power source *i. e.*, the pointers on the ammeters suffered a steady drift to and fro so that the exact balance lasted for a moment only.

It must always be remembered that this is a zero method. Thus an error is introduced if the current either in the heavy or light circuit suffers a momentary and periodic fluctuation

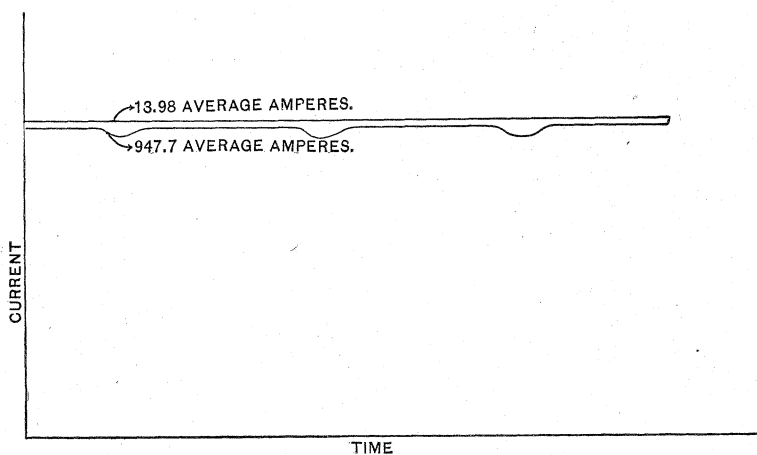


FIG. 11.

that is not common to both circuits. For example, when the current in the last test was increased to 950 amperes, trouble at the commutator of the 2-volt machine appeared. The brushes and commutator are too small for the delivery of so large a current. The pointer on the heavy current instrument showed a momentary periodic depression as indicated in Fig. 11. Since the balancing current had to be furnished at a higher pressure than two volts, it was taken from a separate 110-volt generator. The balancing current suffered no corresponding fluctuation in value. It is evident that the balance would be obtained at the higher value of the fluctuating heavy current. Since the instrument indicates the values of the average currents, it follows that the ampere turns in this instance will be too high. To study

this source of error the current of 950 amperes was passed long enough to obtain five sets of readings. The following result is the average of this set :

Amperes.	Ampere Turns.	Ratio.
947.7	951.7	.9958.

The error due to this cause in this instance was, therefore, .4 per cent.

In practice, a case of this sort is not likely to be found. Where there are periodic and momentary fluctuations of the heavy current, the balancing current will be drawn from the same source, suffering practically the same fluctuations, thus eliminating the error. The above instance in our test is a highly aggravated case, and yet the error is within one half per cent.

In conclusion, I should state that I am well aware that this method of standardizing direct current instruments will look complicated to many. I would heartily recommend that they do not pass judgment upon it in this respect until they have given it a fair trial. The necessary apparatus is simple and inexpensive in each instance. It may be applied anywhere, and operates conveniently even with a variable power. The ampere links can be slipped over the circuits at the back of the switchboards once for all, or they may be slipped over the switch blades at the front, and instruments quickly and accurately checked up at any time by reference to a small instrument that is known to be correct, or which has recently been calibrated.

I wish to express my thanks to my colleagues, Mr. Henry H. Norris and Mr. George L. Hoxie, and to my students, Mr. H. E. Cowing and Mr. F. Martin, for their hearty and effective co-operation in conducting the experiments which resulted in the development of this method for the determination of large direct currents.

Department of Electrical Engineering,

Sibley College, Cornell University, April, 1901.

DISCUSSION.

THE PRESIDENT:—Professor Ryan's ingenious arrangement is to me one of the most novel departures in measuring instruments that I have seen for some time. The idea of using a transformer for direct currents would not be likely to suggest itself to many, and the way in which he has solved the problem of thus applying a useful property of transformers, is certainly extremely ingenious.

The arrangement which he describes must naturally compete with the use of a standard low resistance and a milli-voltmeter. In his paper he has not brought out the advantages which his method will have over this older one, but I presume he will make this clear in the discussion. The paper is open for discussion.

MR. GEORGE T. HANCHETT:—I do not wish to be understood as criticizing, but rather asking for information. There are one or two points which I would like to have brought out. I understand, turning to Fig. 1, that the alternating current voltage used to excite the coil A is obtained by means, I presume, of a sleeve carrying two slip rings, which are respectively connected with the two halves of the two-part commutator adjacent. Now, if a dynamometer instrument were placed upon the terminals of the coil A, a certain deflection would be noticed. As the commutator began to turn, there would be times when the coil A was not connected with the circuit at all, for if the brushes were allowed to bridge between segments 1 and 2, it would constitute a short-circuit between the rings 1 and 2. This introduction of a series of short periods of no voltage on the coil A, would, it seems to me, materially affect the deflection of the dynamometer instrument connected across its terminals, and similarly affect the voltage obtained at the slip rings 3 and 4, and therefore the maximum deflection of the galvanometer or instrument G, would depend, not only on the permeability of the core C, but on the speed of the commutator, which should therefore be a constant quantity. Am I right in that understanding?

PROFESSOR RYAN:—If I may at this time answer the two points—first, as to the matter of bridging over the segments mentioned, it will be noted that the reversal of the direct current occurs at that point as described, in the first commutator. The galvanometer is connected firmly at that very instant, to the middle of the two sectors on the galvanometer commutator. It is just at the instant of the reversal of the direct current that you get electromotive force. There is therefore no trouble of the character which may be thought of as possibly occurring because of the short-circuiting during this short contact of the segments.

Then as to the speed of the commutator. It is true the electromotive force depends entirely on that speed. Nevertheless the observer at the water rheostat is in full touch with any variation of speed that may be occurring in the driving mechanism

for these commutators; he is constantly running the water rheostat handle up and down, and he is entirely conscious of any change in speed that there may be on the part of the driving mechanism or the commutators, or on the part of the machinery that is developing the current. One cannot tell at the galvanometer *G* in this figure, and at the water rheostat, which cause it may be — either or both, for that matter, but you have entirely at your control the means for distinguishing between a maximum deflection that has come from your own act of adjustment of current, or from that which is due to the upward or downward drift of speed. That is a point, however, which actual experience with the method can only bring out, the conviction that this feature is all right.

MR. GANO S. DUNN:—On page 183, Professor Ryan says: "Where there are periodic and momentary fluctuations of the heavy current, the balancing current will be drawn from the same source, suffering practically the same fluctuations, thus eliminating the error." I do not know that I correctly understand that. It seems on reference to Fig. 1, that if the current passing through the instrument *A-E*, and going through the one heavy convolution around the little transformer, were to vary suddenly, that would not necessarily make the current in coil *B* vary equally, and consequently always balance it, because the current in coil *B*, as it is drawn here, appears to be taken across the poles of the generator *D, C*, in other words, in proportion to the voltage of the generator. Whereas the current in the coil *A* is current that is actually being drawn from the generator. The reason I ask this question is that if I understand the diagram right, this arrangement will not permit you to get increase of current, but only measurement of current at particular values, after which particular values you must adjust by hand the water rheostat *H*. If this is the case, its usefulness, while still exceedingly great, is limited more to calibration than to indication. I sympathize with Professor Ryan in regard to the costs of connecting up instruments for measuring large currents. It is only within the last few days, in connection with my work, that I had to authorize the expenditure first of a hundred dollars or so for the shunt, and a milli-voltmeter, and then nearly another hundred dollars for heavy copper castings and lugs and conductors and tips and bolts and things, in order to make these other parts useful, and some way to avoid that is very desirable. But from what I read in the paper, I do not understand that Professor Ryan intends his method to be used, for instance, where a set of observations are desired, under a condition of varying current, as in the case of dynamo testing, with the loads continually varying.

DR. SHELDON:—On page 169, in the second paragraph, the statement is made that "Where two direct current carrying coils of similar dimensions are placed side by side and linked with a closed laminated iron core of low reluctance the permeability of this core for alternating magnetic flux will be a maximum when

the ampere turns of the two coils are equal and opposite." I should think that two coils of that character would exactly neutralize each other, and therefore there would be no magnetomotive force. If that were the case, the iron core would be exactly in a neutral condition. Now, if the iron core have the ordinary form of magnetization curve with the instep, the shin, the knee and the thigh, the permeability, which is equal to the flux density divided by the magnetizing force, would be a maximum not when there is a zero-flux, but when the iron is magnetized in either one direction or the other to a point somewhere near the knee of the curve. The indication on the electro-dynamometer, G , would be a maximum when there was an excess of ampere turns in either the large current coil or the low current coil; that is, at the exact neutral magnetic condition of the iron when the two magneto-forces are exactly equal and opposite, it would not give a maximum deflection in the electro-dynamometer.

PROFESSOR RYAN:—If I may answer these questions at this point it will facilitate my keeping them in mind during the discussion. As to the point, first of all, brought up by Mr. Dunn, I should be sorry if the paper were interpreted as though I meant to advocate that this method should be used for any other purpose than merely to calibrate instruments of the milli-voltmeter and shunt type already installed. If one must put those instruments into circuits for the measurement, presumably with laboratory facilities, they have been calibrated with reference to low resistance standards. But the method is intended more particularly for the calibration of switchboard instruments that are very excellent if one simply knows their constants or knows that they are right as to adjustment. It is a zero method, and Mr. Dunn is right in calling your attention to the fact that as such it can have no practical value for any other than calibrating purposes. It is to avoid the trouble that he spoke of, of having to make the expensive and troublesome heavy current connections for checking up instruments, that this method is to be used. Station instruments as now ordinarily made can very well be used for testing purposes, or for the ordinary purposes that come up as duty in the station, if one only knows, after they have been used for some time, what their character is as to adjustment—knows that they are right, or if they are off, how much they are off.

As to the point that Dr. Sheldon has just now brought forward with regard to magnetic action that goes on in the magnetic circuit, the very reason why we have adopted the alternating current test here, or rather permeability to alternating flux test, is in order that the trouble of all sorts that comes from the irregular portion of the $B-H$ curve of iron will be eliminated. We thought of a great many plans by means of which we would not have to resort to the driving commutator and the alternating permeability test that we have finally adopted in that method, and found none so satisfactory as this. On thinking the matter over and remem-

bering the nature of iron on the basis of the B-H curve, you will remember that permeability for reversal under magneto-motive force is a maximum so long as it is being done symmetrically about the axis. Anything that offsets it in regard to the zero line gives you a smaller range of travel for a given alternating effect plus a constant effect than you otherwise would obtain.

DR. ARTHUR E. KENNELLY :—The paper is interesting, if only for illustrating the modern tendency to turn to alternating currents when we encounter difficulties with direct currents. A short time ago we had so much difficulty in calibrating alternating apparatus that we used to have recourse to direct-current methods. Now the tables seem to have turned, and Professor Ryan goes to alternating currents in order to facilitate direct-current calibration.

The plan, as I understand it, is both interesting and ingenious, and consists in determining when there is zero-flux in a magnetic circuit operated upon by two continuous magneto-motive forces in opposite directions, one being from a single turn, carrying the powerful current to be measured, and the other being from many turns, carrying a small measured current. If I understand the matter correctly, and I have only just seen the paper, the alternating-current theory applies in the manner suggested by Professor Ryan just now, inasmuch as for cyclical alternations their amplitude is greatest, as he says, just at the zero point of flux in the magnetic circuit, although for direct-testing currents the criticism made by Dr. Sheldon would no doubt apply. There is one difficulty that occurs to me, and that is in regard to hysteresis. Suppose the big current through the single turn were applied first; that would magnetize the iron up to a certain extent. Then suppose the small current applied through the many turns. Although the two magneto-motive forces might be equal, and might have zero effect if turned on simultaneously, there might be, under the preceding conditions, a residual magnetism, due to hysteresis, and I suppose that unless that is wiped out by the testing alternating current the permeability would be affected thereby and the results vitiated. I suppose the alternating current must have sufficient magnitude to erase that residual magnetism. I see Professor Ryan indicates that my supposition is right.

It seems to me that the apparatus ought to be very useful for application in power stations and where elaborate apparatus cannot be availed of. But I suppose that Professor Ryan would not recommend this method to supersede, for laboratory testing, the calibration of ordinary apparatus.

PROFESSOR RYAN :—Dr. Kennelly is right in interpreting the view, at any rate, that I have with regard to the alternating current equalizing this hysteresis effect. The alternating magneto-motive force, whatever the difference may be, owing to the coming on at different instants of these two sets of direct magneto-motive forces will cause that difference to disappear. We have found it so. We have been very careful to examine that point. That is

one great reason why we had to come to the use of the alternating magneto-motive force. By no other method, though we tried a great many, could we get over these very difficulties that Dr. Kennelly and Dr. Sheldon have spoken of.

I do not at all wish to put the method in competition with the refined method of adjusting an instrument, the Reichsantalt low resistant heavy current standard, and the Clark cell and the potentiometer, or a laboratory pattern of the milli-voltmeter, as made by an eminent maker of electrical instruments—not at all. But you cannot take your laboratory facilities with you into electric light and power stations, while, with these coils, you can consume very little time in applying the calibrating transformer method. I think it is well to remember that the laboratory methods, using the Reichsantalt standard, while splendid in the laboratory, will consume too much time and require one to use expensive connections for their application in the power house.

MR. C. O. MAILLOUX:—I understand this method to be a zero method, which, however, differs from most zero methods in so far as the indicating instrument does not indicate zero reading when the zero point is reached, but indicates a maximum reading; that is to say, in this case when the point of zero flux in the core of the special transformer is reached, the galvanometer *g* gives the largest deflection. I would like to ask Professor Ryan, if this be the case, whether it would not be possible to make the transformer coil *b*, such that instead of having to step down from the coil *a*, it would step up; in other words, use a coil having a very large number of turns of fine wire, and then simply connect the terminal of that coil to an ordinary alternating current voltmeter. It seems to me that if instead of stepping down and getting a very delicate deflection, he were to step up and decrease the action, that he would then be able to get an action sufficiently great to show indications on the ordinary voltmeter such as are made for alternating current, and as the operation is one which is read by reference to the largest deflection, it seems to me that he would be able to get as good accuracy by that means as by the use of the very delicate milli-voltmeter or of the galvanometer *g*.

PROFESSOR RYAN:—In reply to the point brought up by Mr. Mailloux, we adopted this plan for the reason that there is some practical value, I think, in being able to use one of the milli-voltmeters of the same type that is used for ammeters, that one applies this method ordinarily to, to calibrate. That is, however, but one reason, and rather an unimportant one, I think. The most important factor determining this way of applying the balance test, or alternating permeability balance test, has been that we must not introduce too much activity of an alternating character there, or by mutual induction there will be interference. The method will not have the same integrity that it has with the smaller alternating activity of flux densities and periodicity that

you can so easily make use of by applying the direct current instrument to test for balance through the two-part commutator.

MR. HANCHETT:—Would it be possible to open the magnetic circuit, and introduce therein a D'Arsonval coil neutralizing any residual magnetism, if such occurs, by means of an alternating current coil wound on the same core? A D'Arsonval coil, if a voltage were applied to it, would deflect if there were any flux, and would remain at zero if there were zero flux.

PROFESSOR RYAN:—We began with those models, and had to come to this arrangement. We had that one and a number of other models modified a good bit from the one that has just been brought up, and met with no success. I do not mean to say that final success could not be obtained that way, but we were not able to make progress, and further discussion of the matter as to why not, would involve a number of wee little things that made our experience with the method in attempting to use those models rather a discouraging one for the time being.

MR. TOWNSEND WOLCOTT:—Mr. President, I would like to ask Professor Ryan one question in regard to the maximum. How rapidly does the permeability vary in the neighborhood of the maximum value; in other words, how accurately can the maximum point be determined? Most maxima occur where the differential coefficient of the function is zero, and the rate of change is usually very small in the immediate neighborhood of a maximum, on both sides, and the maximum is consequently difficult to locate accurately by measurement.

PROFESSOR RYAN:—In reply to that matter, I may state that you will find, any of you, in trying the method, that the maximum is very crisply defined. I mean by that, however, that it is defined within such narrow limits in the balancing coil, that the errors of determination are within those that we care anything about for engineering purposes, namely, a quarter of one per cent.

THE PRESIDENT:—I would like to ask Professor Ryan if he found that it made any difference whether the current to be measured is brought from a lower value up to the desired reading, or is brought down to that reading; that is, is the effect of a previous increase or decrease in the main current noticeable? In other words, does the alternating current entirely wipe out a residual magnetic effect that might have been induced by an increasing as distinguished from a decreasing current?

PROFESSOR RYAN:—We have found that it does, with the proportions that are advised in this paper. You are not able to distinguish as to the value obtained, whether you come to the balance by bringing the balancing current there from a lower value to a higher value, and thus to the balancing point, or by first going up and then dropping down to it; the same values are obtained either way.

THE PRESIDENT:—That is, because you use an alternating current in the testing apparatus?

PROFESSOR RYAN:—Yes.

THE PRESIDENT:—It would probably not be the case if the arrangement just suggested by Mr. Hanchett was used, because there would probably be an after effect of the current.

PROFESSOR RYAN:—There would be that, and the insertion of a gap in the core induces many troubles.

THE PRESIDENT:—Do you not have to be very careful about the magnetic leakage? In other words, do not the windings of the two direct currents have to be in very close proximity to each other and absolutely symmetrical with each other? Because it seems to me that if there is magnetic leakage between them, due to those strongly magnetizing currents, it would produce quite an error in the reading.

PROFESSOR RYAN:—The matter just referred to we went into quite carefully, and find that by adopting the type of transformer, as stated in the paper, and which I illustrated by means of a lantern slide, and disposing of it in the manner there shown, one is not then called on to incur any risk in this respect whatsoever, according to our experience. In other words, the disposition of the balancing coil and its core, with reference to the conductor carrying the heavy current, must be such as to produce a local field on the part of the one coil through the core that is not pronouncedly different from the local field that is produced by the other conductor or coil. Now for the core that passes around the conductor, with the balancing coil mounted upon it, going entirely around that core, and giving to the core and the balancing coil thereon wound, an outline that corresponds to the conductor cross-section, one incurs no risk of error in this respect whatsoever, according to our studies. The case, for example, that we had on the screen, that same coil which we there used for calibrating the 4,000-ampere ammeter, we used likewise on a 750-ampere circuit, where the conductor carrying the current was very much smaller. We placed that at the center of the rectangular core. Immediately on one side was the equalizer blade of the same switch carrying current. That, however, would not produce error, because any stray field that it sets up is in common with the magneto-motive force action of the balancing coil and the main conductor that is carrying the heavy current that passes through the balancing coil. With that design of transformer that is here advised, whatever leakage defects there are, they occur in such a respect that there is no interference with the indication of the true balance. The balancing coil does not present in effect more ampere turn than the actual number that it possesses, nor does it present less.

There being no further discussion, the following paper by Professor F. W. Brady on "Electricity in Mountain Mines" was read by Dr. Sheldon for the author.